

Steering Through Change, i.e. the Greatest Long-term Challenge(?)

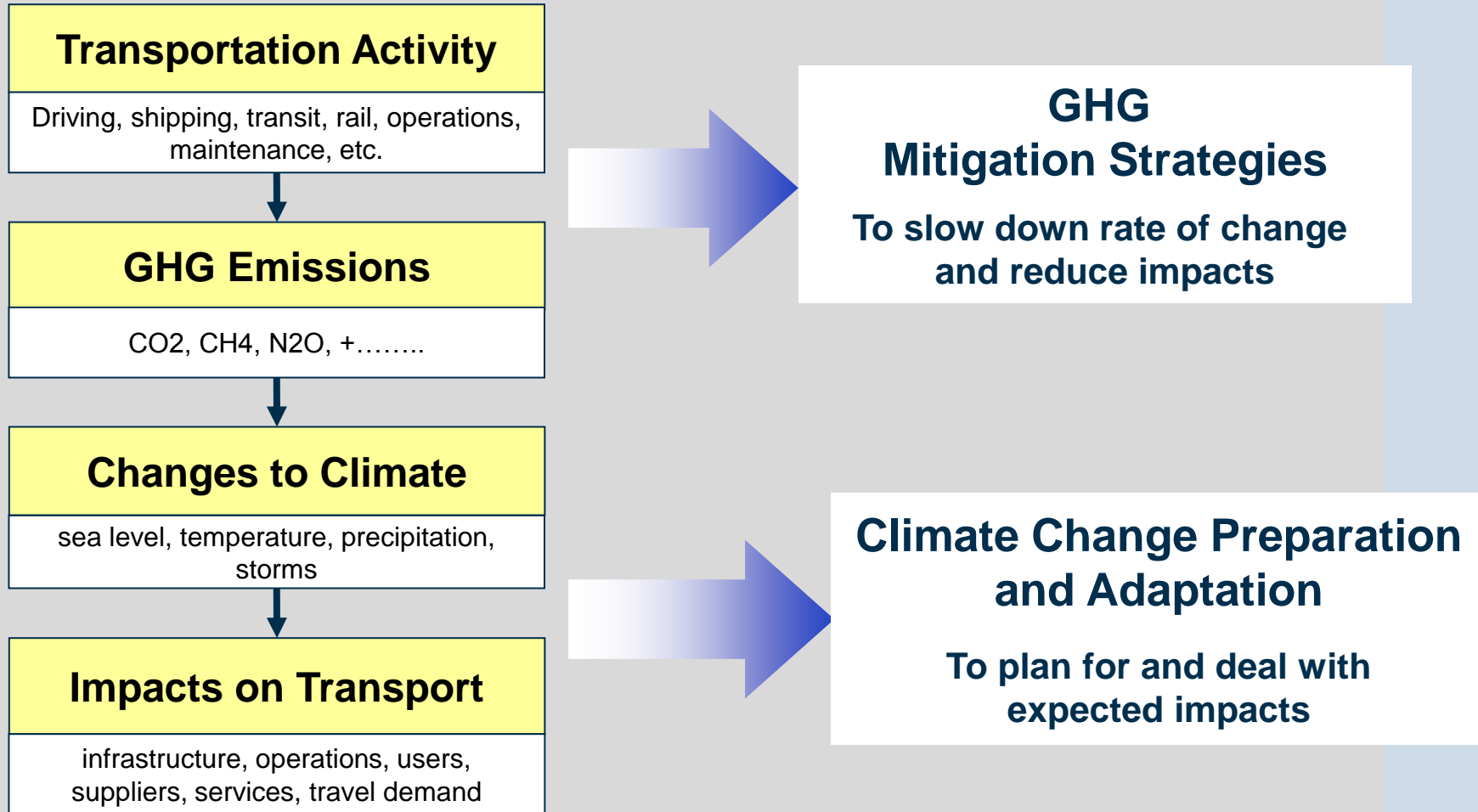


**NORTH CAROLINA PUBLIC
TRANSPORTATION COMMUNITY
TRANSPORTATION CONFERENCE**

Michael D. Meyer

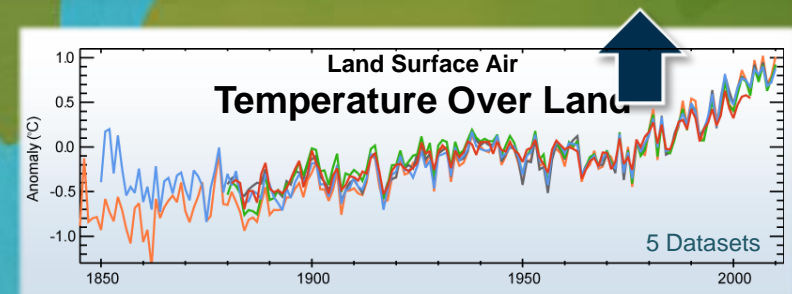
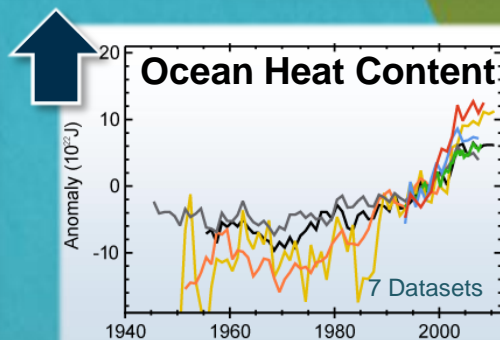
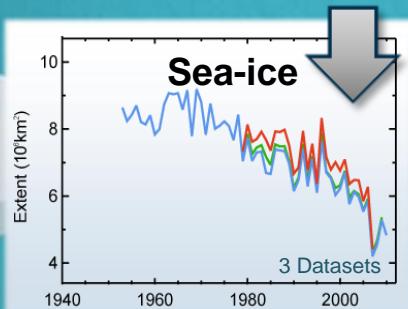
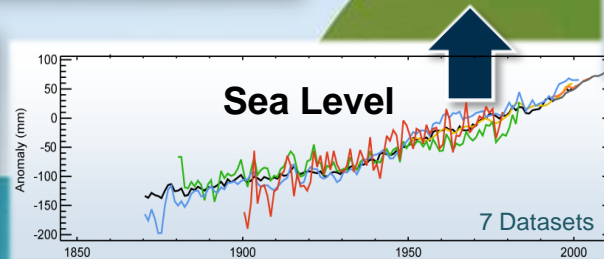
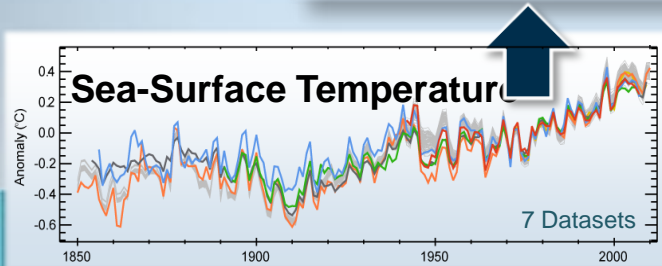
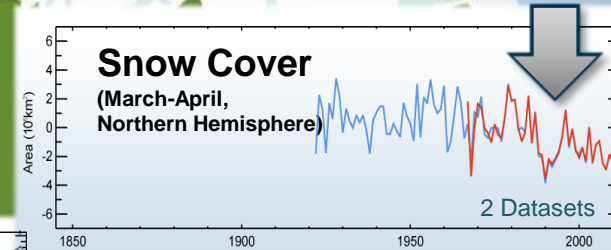
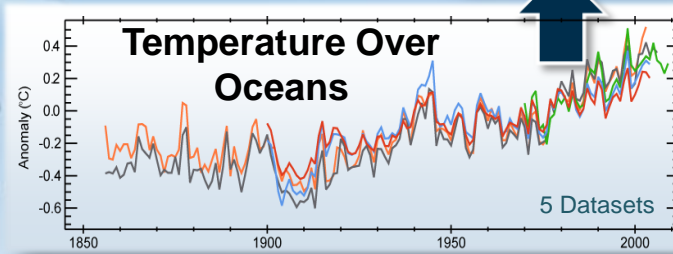
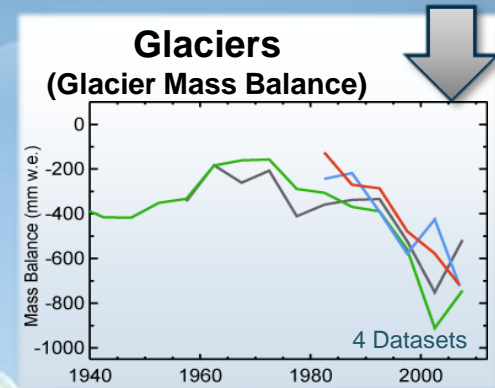
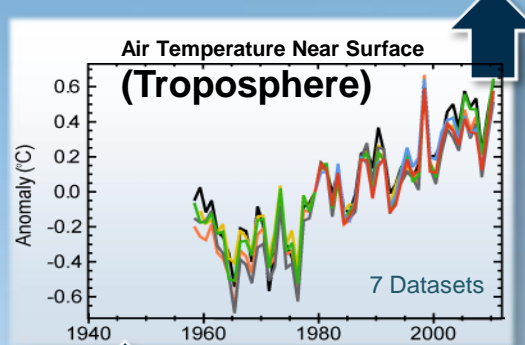
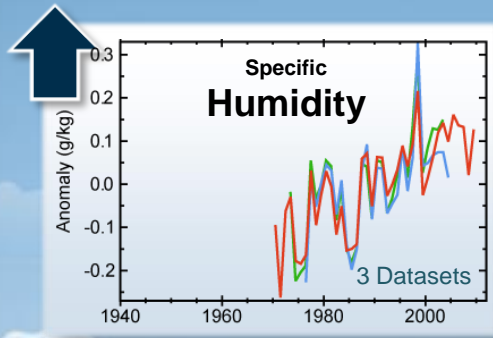
**PARSONS
BRINCKERHOFF**

What is the Difference between Mitigation & Adaptation?



The Changing State of the Climate

Updated from Bulletin of the American Meteorological Society, 2010-12



Extreme Events



Katrina



Katrina



Katrina



Katrina



Irene



Irene



Irene



**Before
and
After**

Sandy



Sandy



Sandy



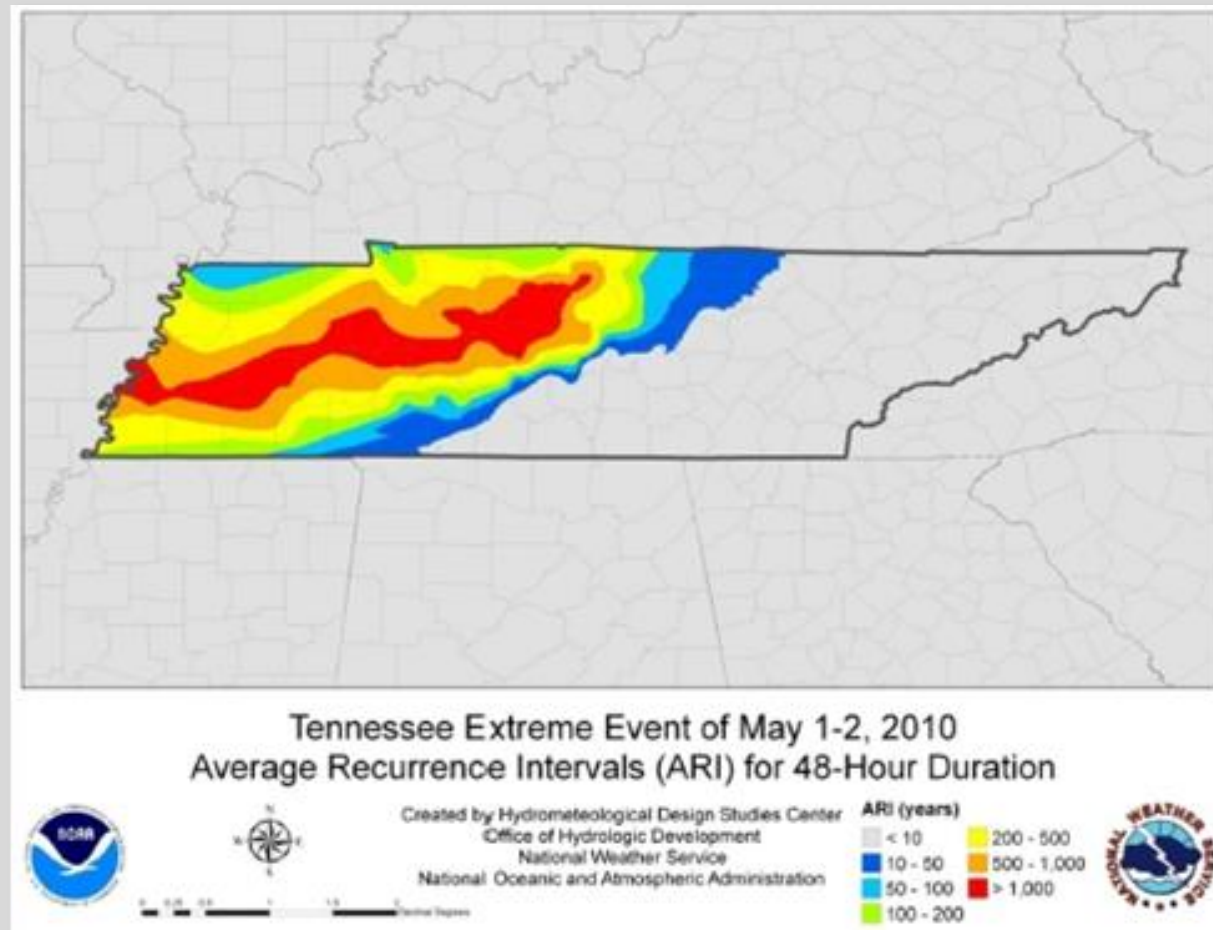
Sandy



Sandy



Tennessee Superflood, 2010



Tennessee Superflood, 2010



Approach Roadway Damage



Structural Damage



Structural Damage



Bridge Scour

Long-term Environmental Changes



Long-term Environmental Changes



Long-term Environmental Changes



Public Transportation



2012--- A Record Year

Hottest March on record in the contiguous United States, and July was the hottest single month ever recorded in the lower 48 states

Worst drought in 50 years across the Midwest and South, with over 1,300 US counties across 29 states declared drought disaster areas.

Wildfires burned over 9.2 million acres, with the average size of the fires setting an all-time record of 165 acres per fire.

Hurricane Sandy's storm surge height (13.88 feet) broke the all-time record in New York Harbor

2012--- A Record Year

California: Total of 37 broken heat records, 5 broken snow records, 53 broken precipitation records, and 102 large wildfires

Kansas: Total of 64 broken heat records, 42 broken precipitation records, and 30 large wildfires

Montana: Total of 59 broken heat records, 16 broken snow records, 17 broken precipitation records, and 128 large wildfires

Texas: Total of 144 broken heat records, 8 broken snow records, 115 broken precipitation records, and 34 large wildfires

Adaptation per the Pew Center on Global Climate Change (as modified)

*“Actions by individuals or systems to **avoid, withstand, or take advantage** of current and projected climate changes and impacts. Adaptation **decreases a system’s vulnerability, reduces risk and/or increases its resilience to impacts.**”*

What is Adaptation?

Climate Changes

- Extreme Precipitation
- Rising Sea Levels
- Temperature Spikes
- ...

Impacts on Transportation

- Roadway flooding
- Damage/destruction of bridges
- Pavement and rail buckling
- Subway flooding
- Seaport & airport flooding
- Slope failures
- Curtailment of barge operations
-

Consequences

- Freight traffic disrupted for days or weeks
- Power plants, water facilities, homes, businesses, hospitals cut off
- Passenger travel delays
- Higher transportation costs for government, businesses, and households
- Evacuations
-

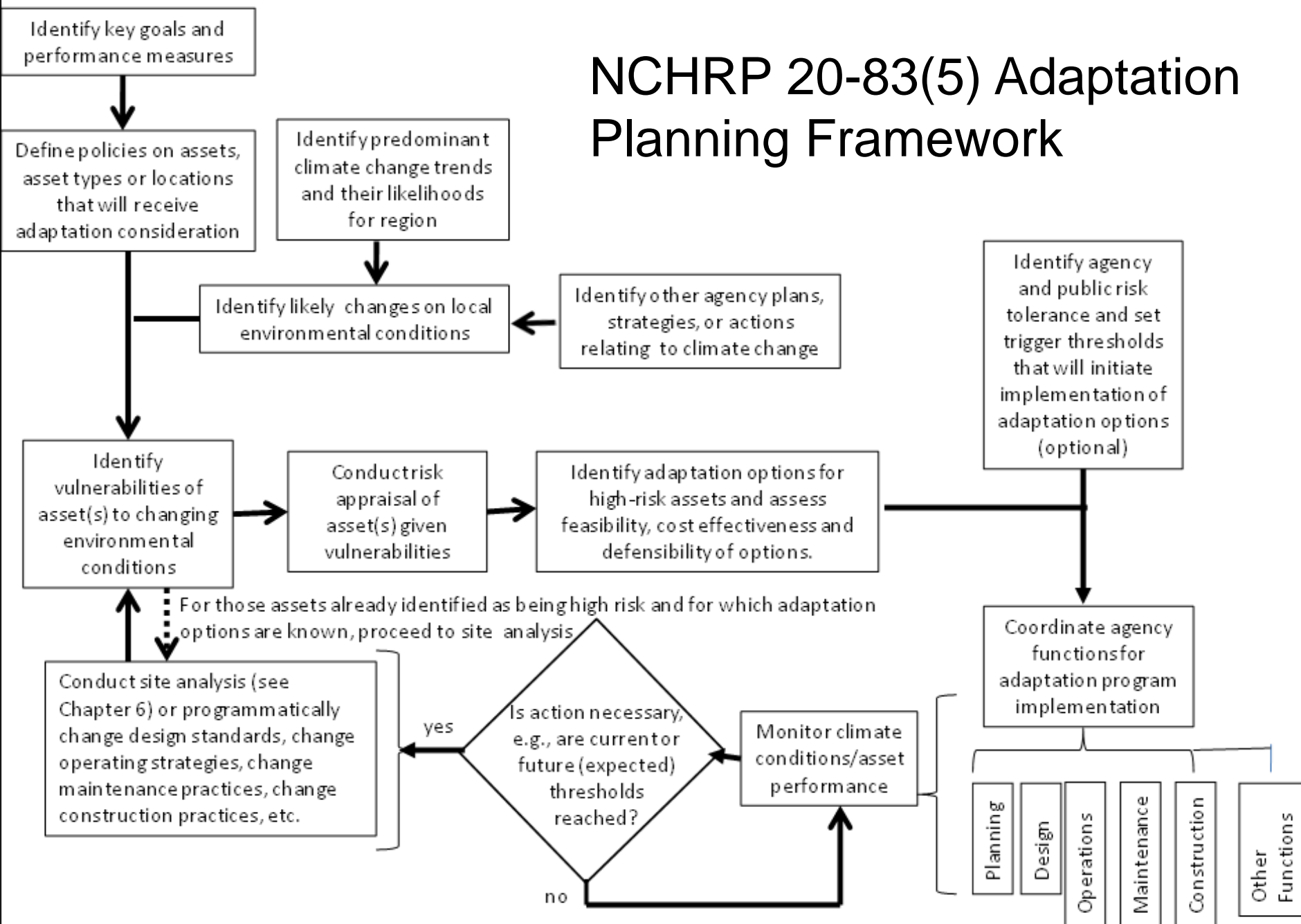
Adaptive Strategies to Reduce Impacts

- Retrofitting facilities
- Relocation of facilities
- Upgraded stormwater drainage facilities
- Building new facilities to climate-ready standards
- Protect existing infrastructure
- Flexible infrastructure design
- Risk-based approach

Adaptive Strategies to Reduce Consequences

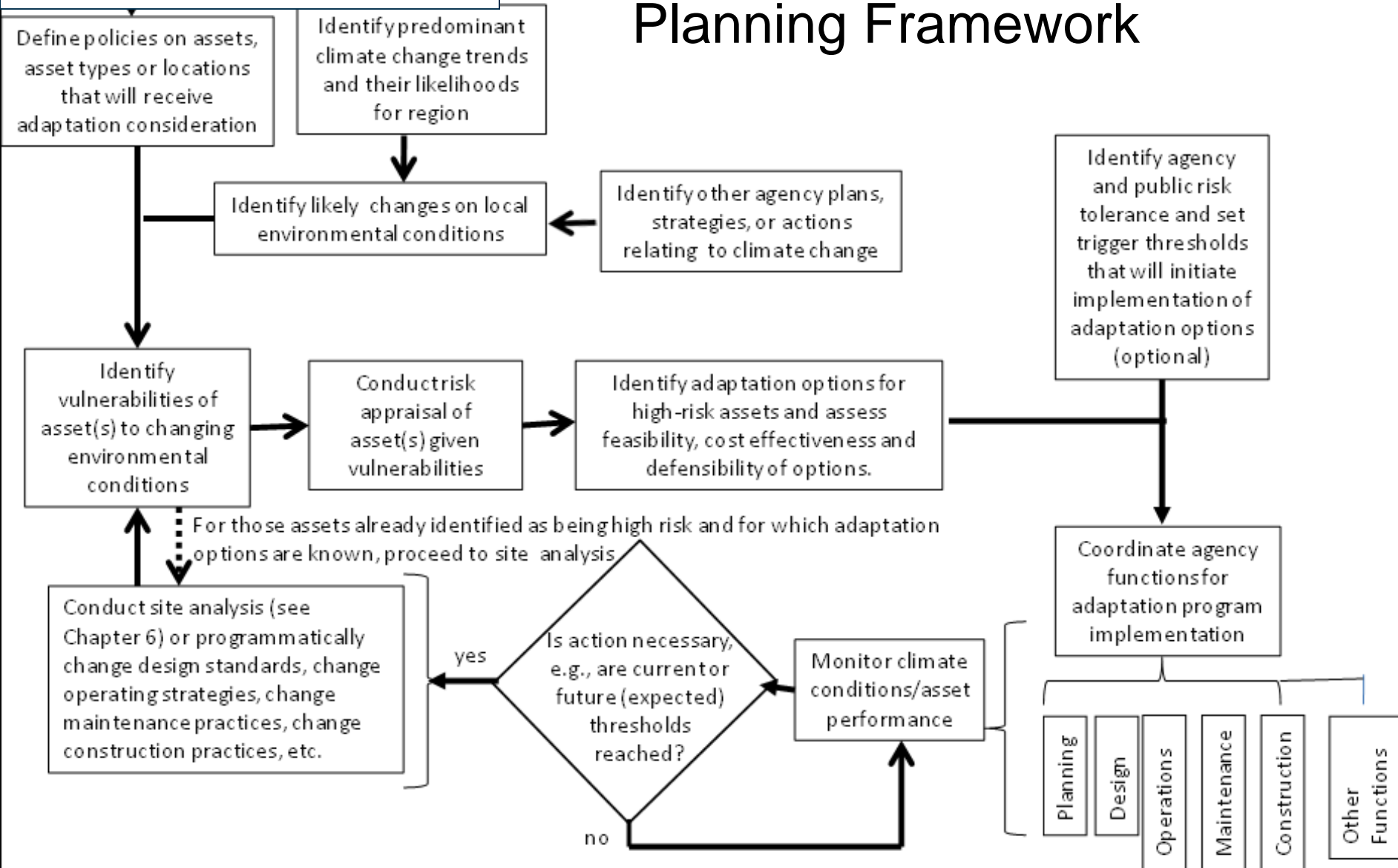
- Reroute freight and passenger flows
- Shift to alternative modes
- Land use regulations relating to development in vulnerable areas
- Evacuation/contingency strategies
- Building in network flexibility
- Traveler information systems
- Rapid rebuilding of damaged facilities
- Improved air traffic management

NCHRP 20-83(5) Adaptation Planning Framework



Identify key goals and performance measures

NCHRP 20-83(5) Adaptation Planning Framework



Identify key goals and performance measures

Define policies on assets, asset types or locations that will receive adaptation consideration

NCHRP 20-83(5) Adaptation Planning Framework

Identify other agency plans, strategies, or actions relating to climate change

Identify agency and public risk tolerance and set trigger thresholds that will initiate implementation of adaptation options (optional)

Identify vulnerabilities of asset(s) to changing environmental conditions

Conduct risk appraisal of asset(s) given vulnerabilities

Identify adaptation options for high-risk assets and assess feasibility, cost effectiveness and defensibility of options.

For those assets already identified as being high risk and for which adaptation options are known, proceed to site analysis

Conduct site analysis (see Chapter 6) or programmatically change design standards, change operating strategies, change maintenance practices, change construction practices, etc.

Is action necessary, e.g., are current or future (expected) thresholds reached?

Monitor climate conditions/asset performance

Coordinate agency functions for adaptation program implementation

Planning

Design

Operations

Maintenance

Construction

Other Functions

Define policies on assets, asset types or locations that will receive adaptation consideration

Identify key goals and performance measures

Identify other agency plans, strategies, or actions relating to climate change

For those assets already identified as being high risk and for which adaptation options are known, proceed to site analysis

Conduct site analysis (see Chapter 6) or programmatically change design standards, change operating strategies, change maintenance practices, change construction practices, etc.

Is action necessary, e.g., are current or future (expected) thresholds reached?

Monitor climate conditions/asset performance

Coordinate agency functions for adaptation program implementation

Planning

Design

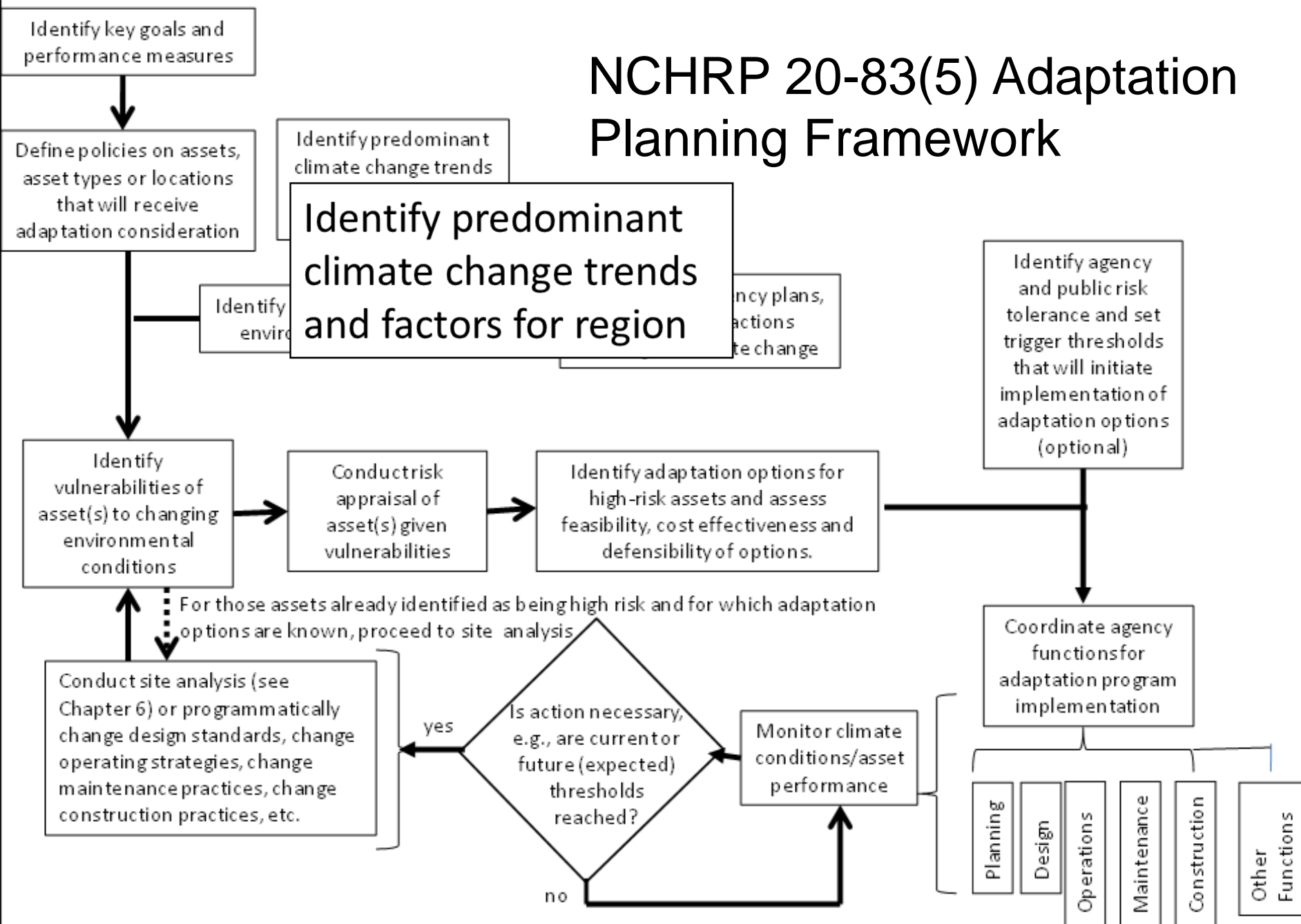
Operations

Maintenance

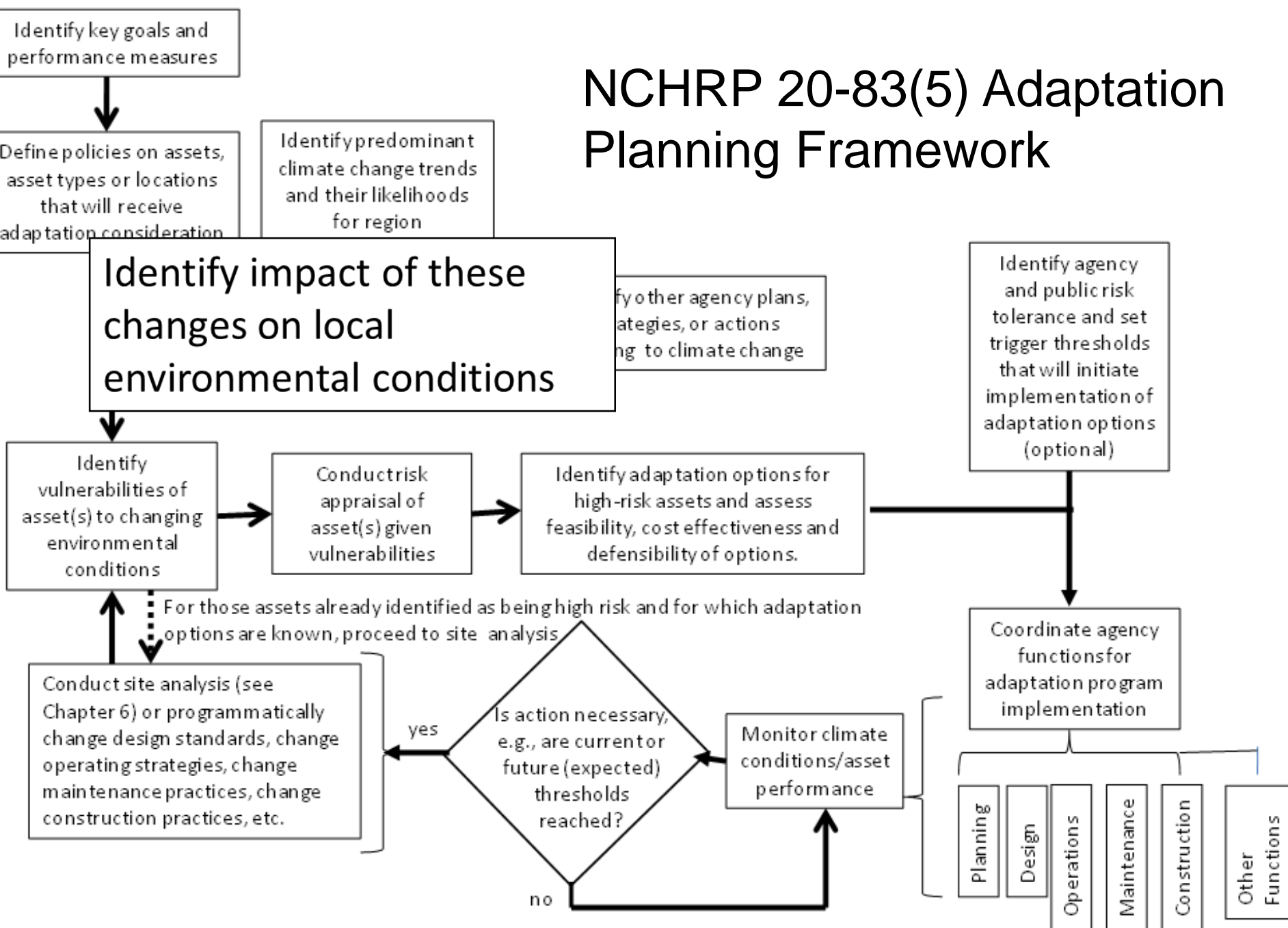
Construction

Other Functions

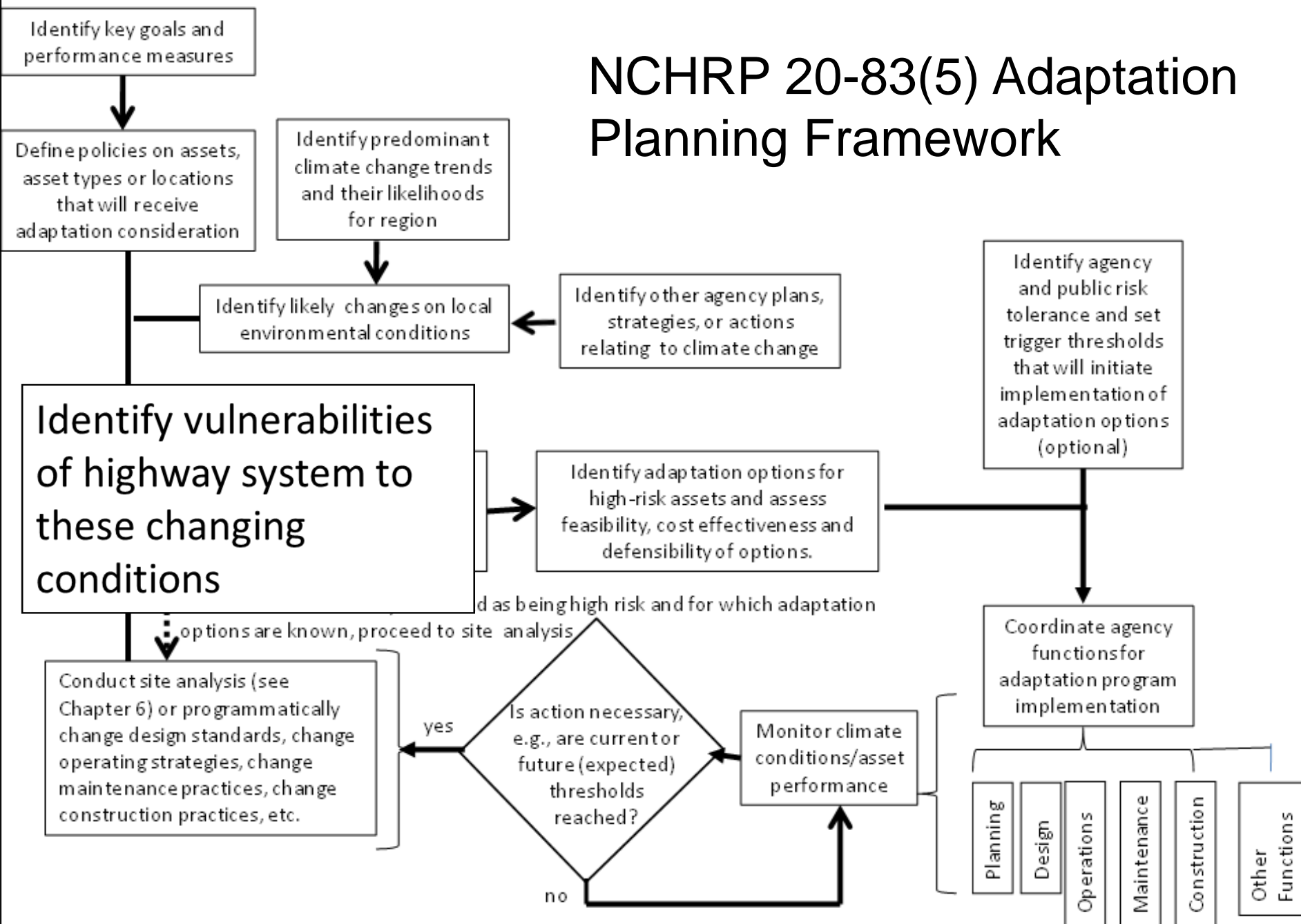
NCHRP 20-83(5) Adaptation Planning Framework



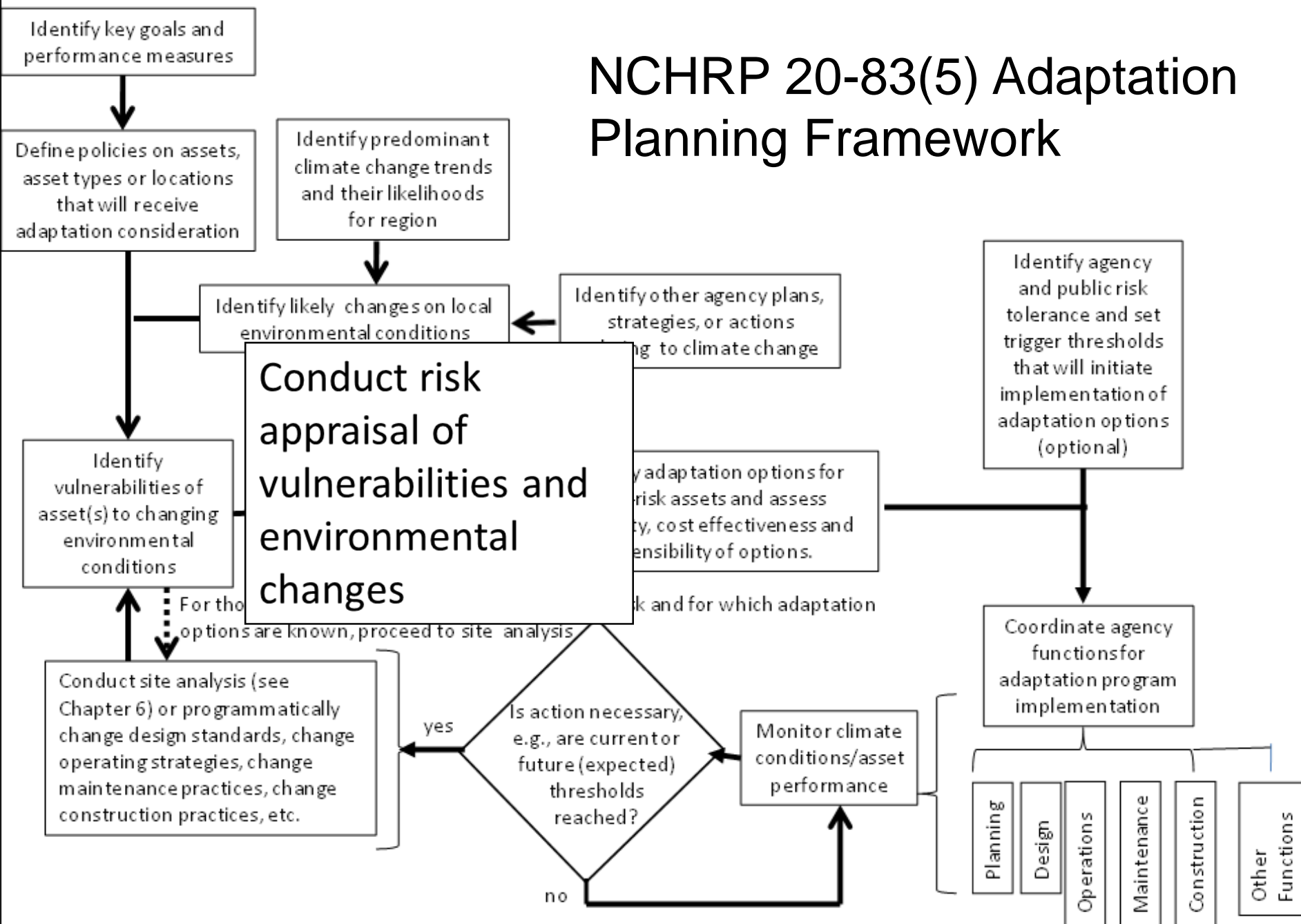
NCHRP 20-83(5) Adaptation Planning Framework



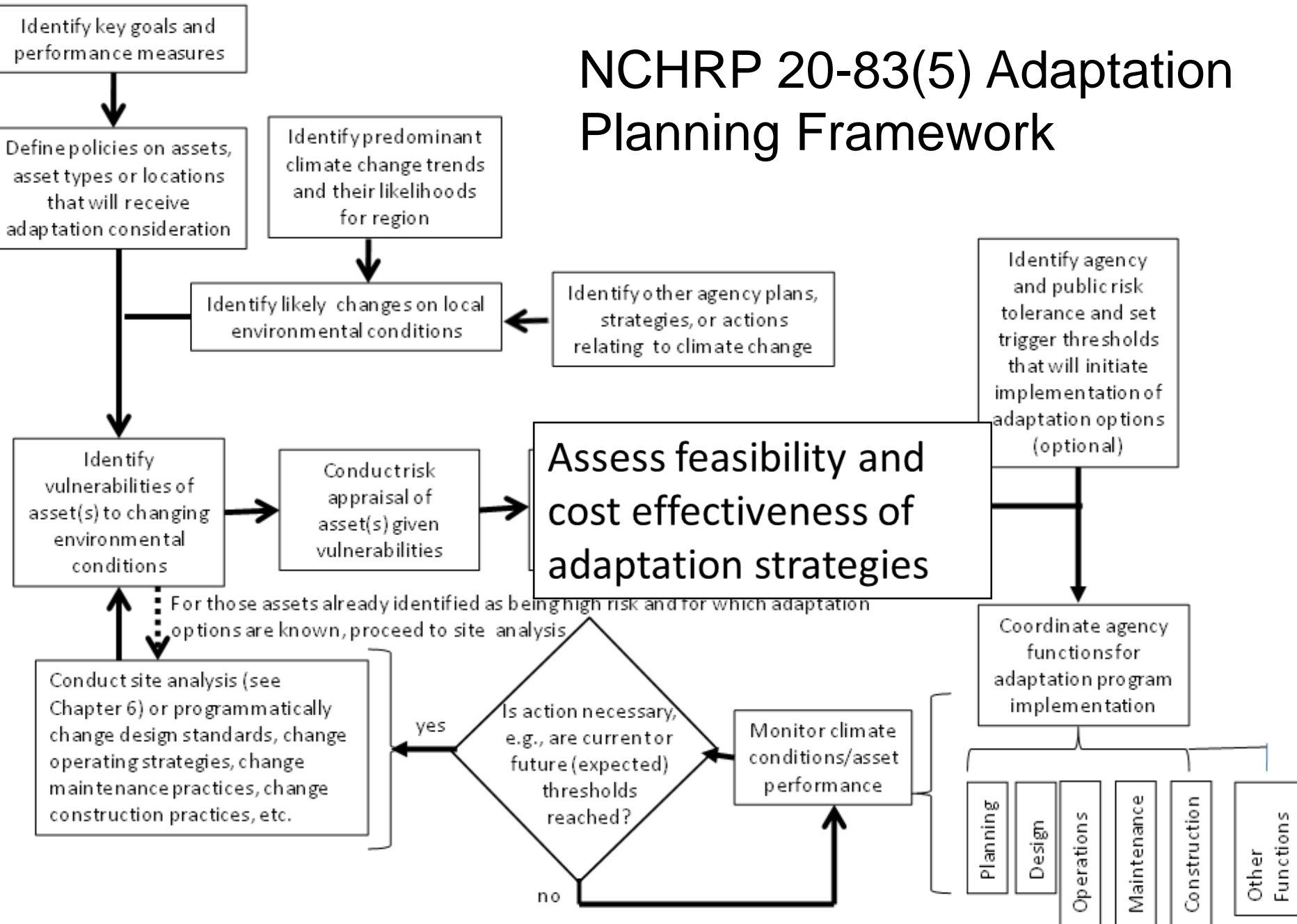
NCHRP 20-83(5) Adaptation Planning Framework



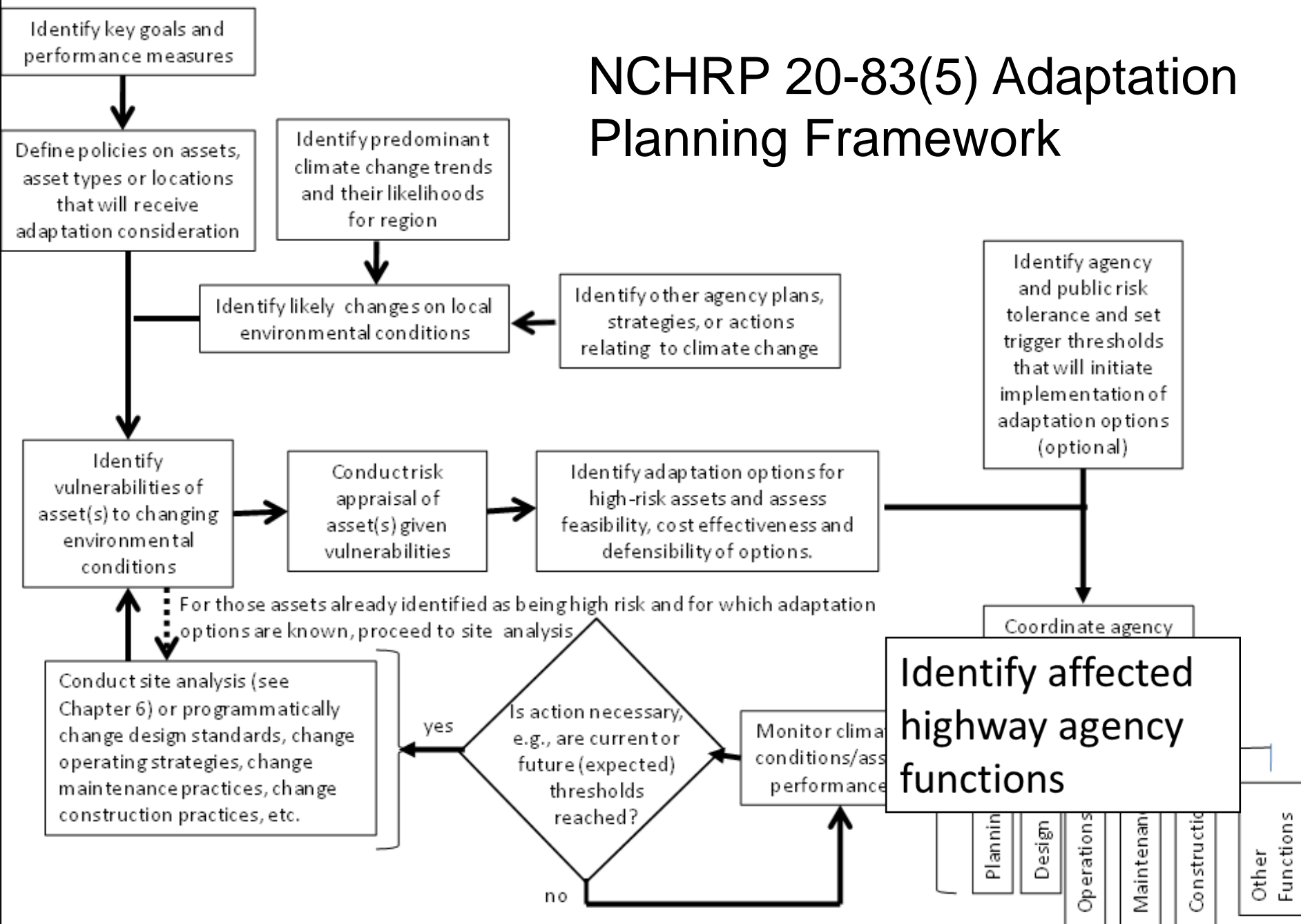
NCHRP 20-83(5) Adaptation Planning Framework



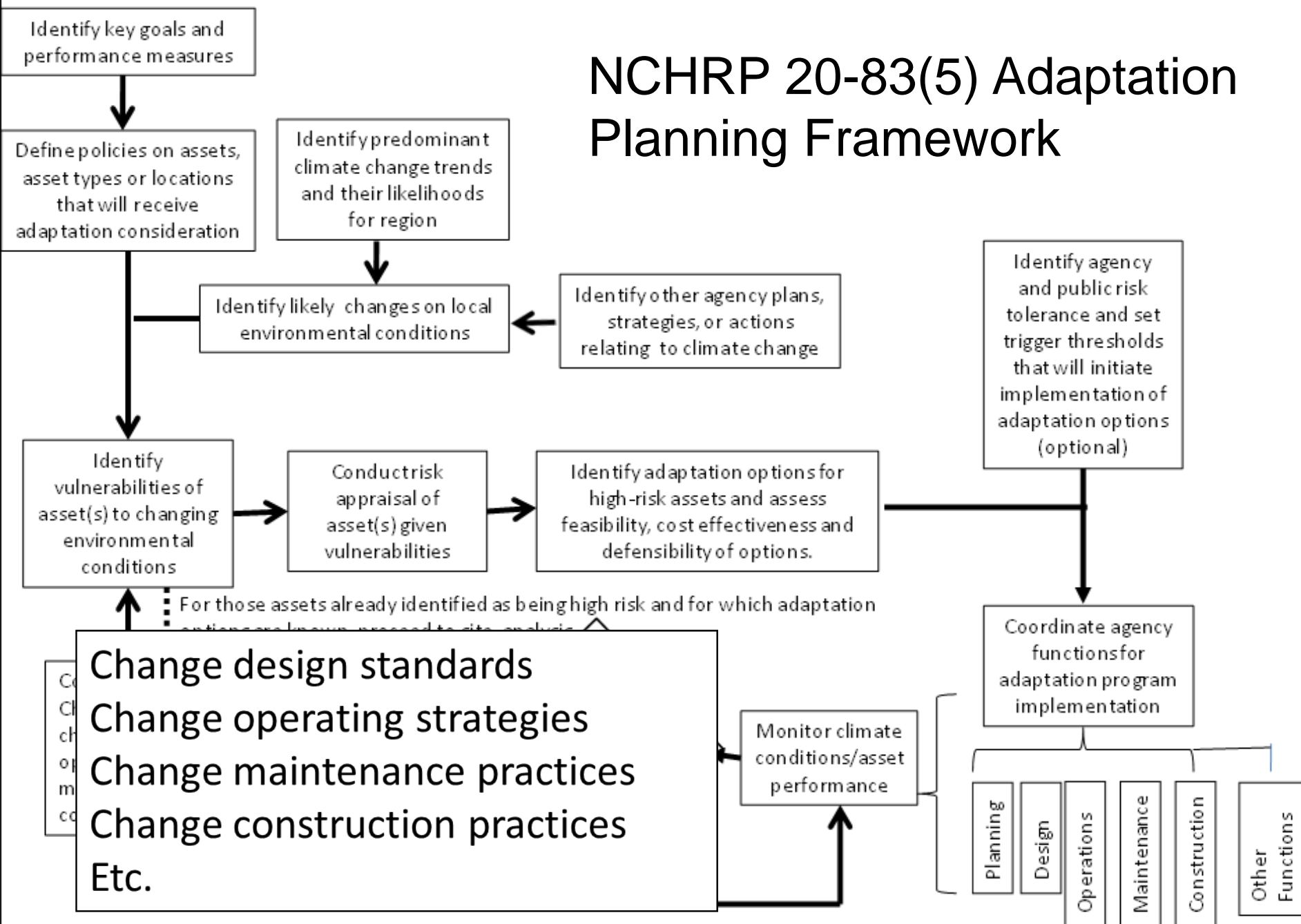
NCHRP 20-83(5) Adaptation Planning Framework



NCHRP 20-83(5) Adaptation Planning Framework



NCHRP 20-83(5) Adaptation Planning Framework



Elements of Risk to the Transportation System

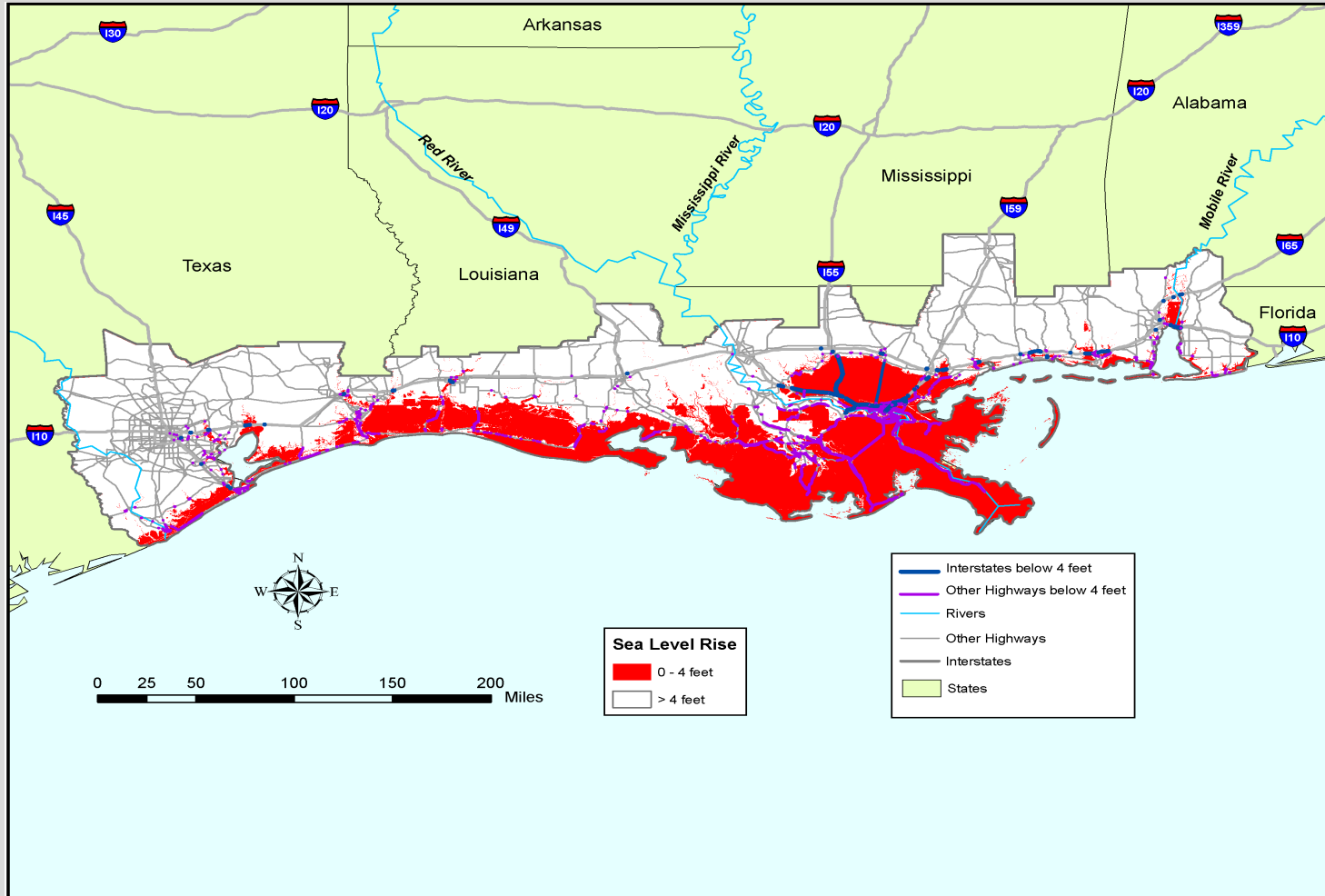
1. Extent of exposure
2. Measure of importance (“criticality”)
3. Climate change-related stresses
4. Level of vulnerability
5. Risk/Adaptive capacity

U.S. Disaster Costs (1980-2011)

	# Events	Damage (\$ billion)	% Damage	% Frequency
Tropical Cyclones	31	\$417.9	47.4%	23.3%
Droughts/Heat	16	\$210.1	23.8%	12.0%
Severe Storms	43	\$94.6	10.7%	32.3%
Non-tropical Floods	16	\$85.1	9.7%	12.0%
Winter Storms	10	\$29.3	3.3%	7.5%
Wildfires	11	\$22.2	2.5%	8.3%
Freezes	6	\$20.5	2.3%	4.5%
Total	133	\$881.2	100.0%	100.0%

2011 Dollars

Gulf Coast, Phase 1: 4 ft SLR



Gulf Coast, Phase 1

Transportation infrastructure that is vulnerable to 18 feet of storm surge includes:

- 51% of interstate miles, 56% of arterial miles, and most transit routes
- 98% of port facilities vulnerable to surge and 100% to wind
- 33% of rail miles operated, 43% of freight facilities,
- 22 airports in the study area at or below 18 feet MSL
- Potentially significant damage to offshore facilities

2. What is Critical?

Those components of the transportation network that serve functions important (critical) to the viability of the local/regional/state system.

No single set of criteria....jurisdictions creating their own.

GC 2 Assessment of Transportation Systems

Key Aspects of Critical Infrastructure (Theory)

CONNECTION

Connecting Mobile
to the Region &
Nation



PURPOSE

Distribution
Centers
Multimodal Centers



FUNCTION

Access to Employment
Centers, Hospitals,
etc.



GC2 Methodology To Define Critical Infrastructure

Assessment looked at three categories of criticality:

- Socio-economic linkages
- Operations characteristics
- Health and safety provisions

Other Examples: New Jersey

“Collected assets were organized into tiers of criticality, from “Low” to “Extreme” based on their respective roles in connecting critical destinations—in this case approximated by a combination of population and job density.”

Climate Change Vulnerability and Risk Assessment of New Jersey's Transportation Infrastructure

http://www.njtpa.org/plan/Element/Climate/documents/CCVR_REPORT_FINAL_4_2_12_ENTIRE.pdf

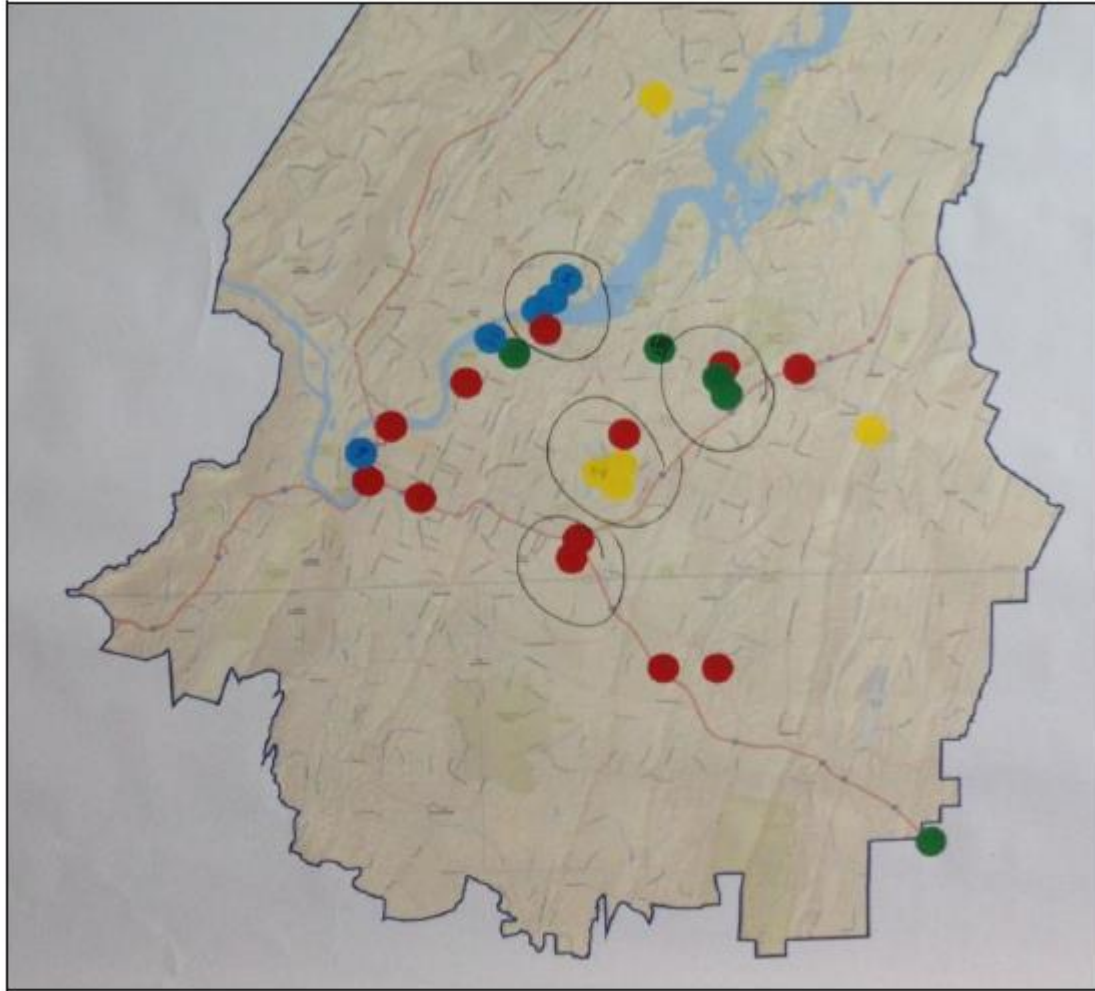
Other Examples: Hampton Roads

“Four screening criteria were used (1) assets on hurricane evacuation routes; (2) assets that carry high traffic volume (AADT>10,000 vehicles/day); (3) assets that represent a maintenance priority route (e.g. snow removal priority route); and (4) those that are at low-lying elevations.”

Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure, Hampton Roads

http://www.virginia.edu/crmes/fhwa_climate/files/finalReport.pdf

Other Examples: Chattanooga



Public Exercise
to Identify
Critical Assets—
Place Dots

Other Examples: Chattanooga

Asset	Why?
Chickamauga Lock and Dam	<ul style="list-style-type: none">• Movement of freight and people• Flood mitigation• Quality of life
Metropolitan airport	<ul style="list-style-type: none">• Freight, jobs and interregional commerce• Tourism• Potential intermodal hub
I-75 and I-34 interchange	<ul style="list-style-type: none">• Major regional interchange
Tennessee R. bridges	<ul style="list-style-type: none">• Multimodal access• River transportation
Volkswagen Enterprise South Area	<ul style="list-style-type: none">• Jobs• Health services

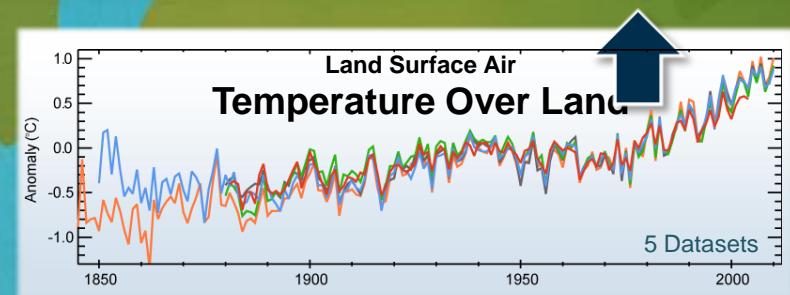
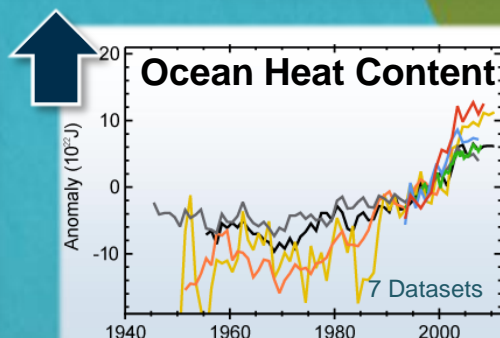
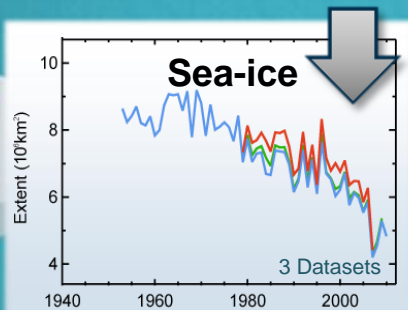
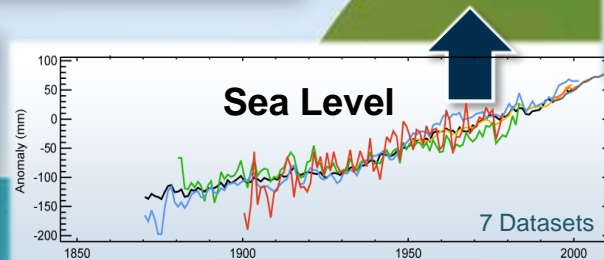
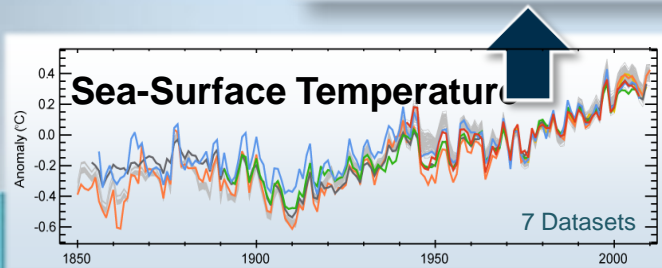
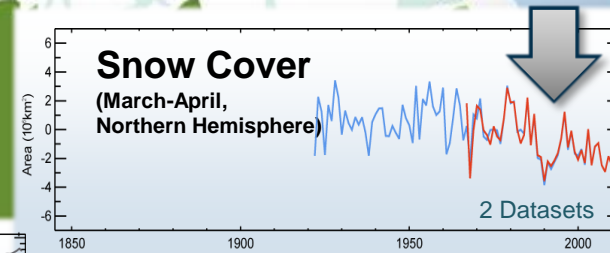
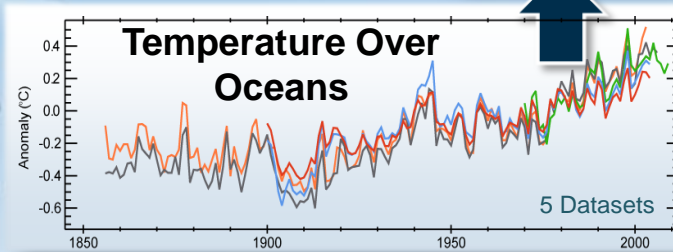
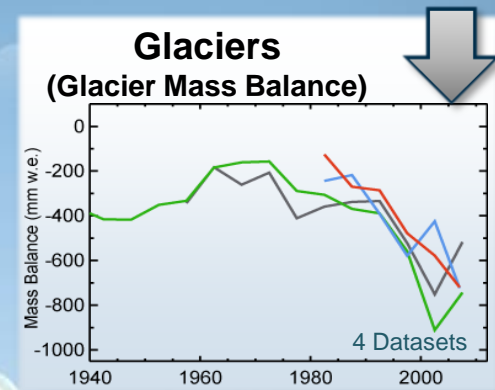
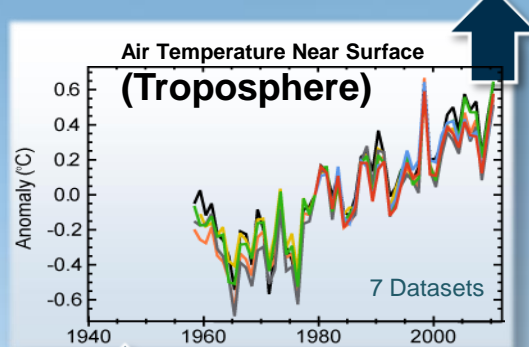
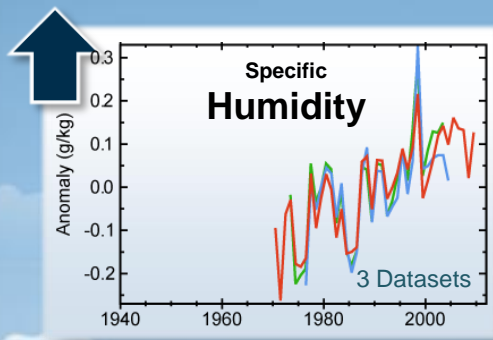
3. Climate Change-related Stresses

Or.....

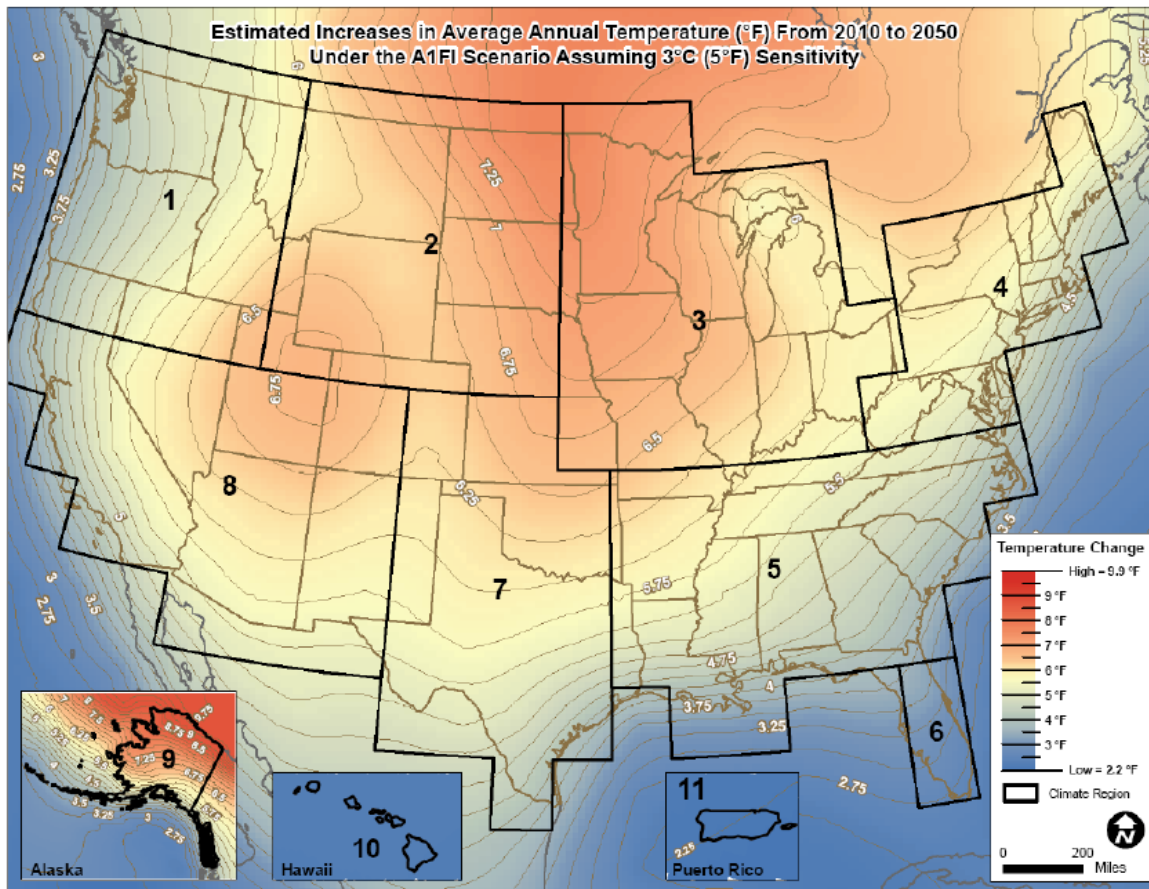
Adaptation in response to what?

The Changing State of the Climate

Updated from Bulletin of the American Meteorological Society, 2010-12

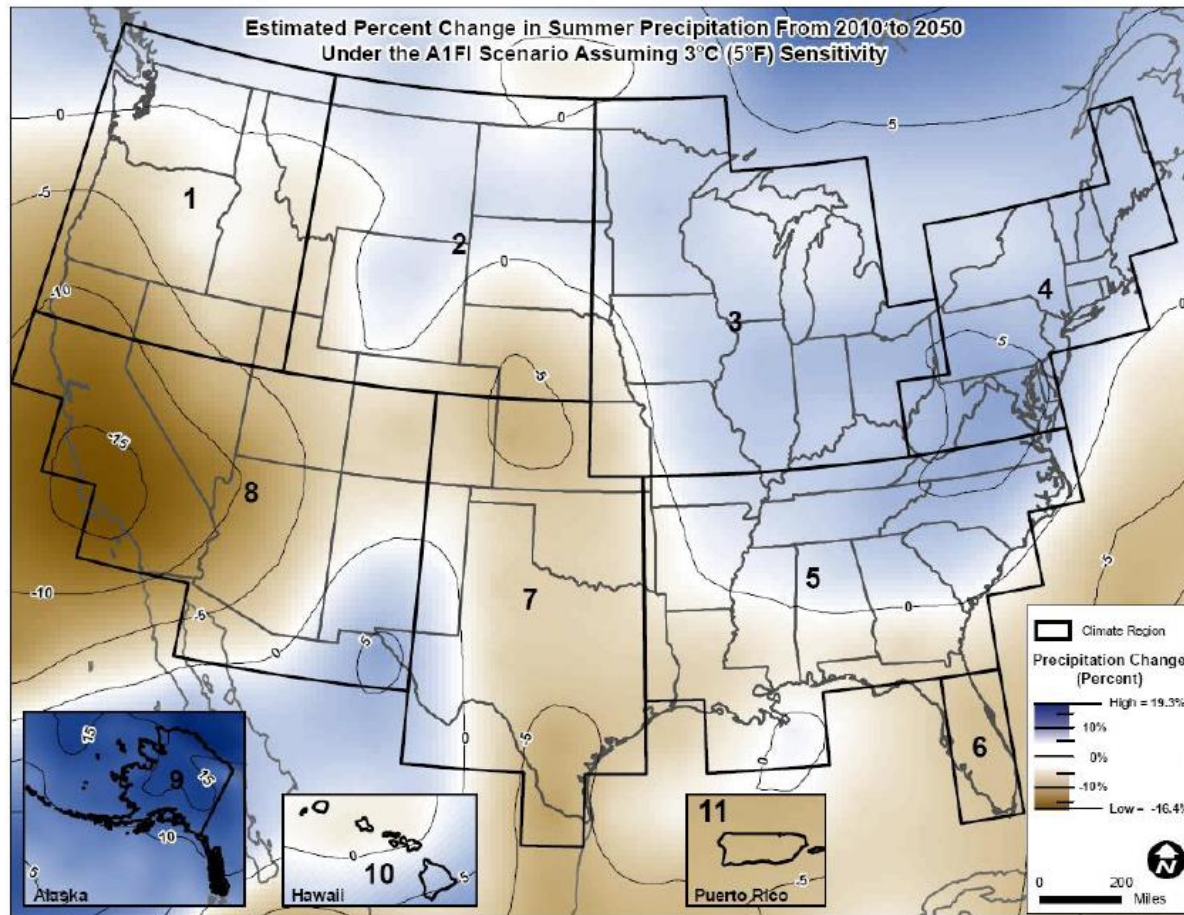


Expected Change in Temperatures



**Estimated Increases in
Temperature in 2050
Relative to 2010, A1F1
Scenario, 3° Sensitivity**

Expected Change in Precipitation



Percentage Change in
Annual Precipitation in
2050 Relative to 2010,
A1F1 Scenario, 3°
Sensitivity

**PARSONS
BRINCKERHOFF**

Heat Waves

National and Regional Trends Regional Trends	Projections
<p>Nationally-averaged, more frequent high temperatures and heat waves</p> <p>Many recent record-breaking hot summers</p> <p>Strongest trends in West, less warming in SE</p>	<p>Increases in severity and intensity in all regions</p>

Joe Casola, C2ES
Staff Scientist, Director of Science and Impacts
Center for Climate and Energy Solutions

Drought and Wildfire

National and Regional Trends Regional Trends

Country as a whole has gotten slightly wetter, led by Northern areas. Southwest has gotten slightly drier.

No strong drought trends; periods of intense drought have periodically occurred in different regions

More area burned in wildfires
(management likely plays a role)

Projections

Droughts expected to be exacerbated by higher temperatures

Decreases in rainfall in the Southwest expected to increase frequency/severity of drought

Wildfires expected to be more extensive and severe

Joe Casola, C2ES
Staff Scientist, Director of Science and Impacts
Center for Climate and Energy Solutions

Wind Events: Tropical storms, Tornadoes, and Strong Storms

National and Regional Trends Regional Trends	Projections
<p>Tropical storms have become more intense in the Atlantic basin</p> <p>No clear trend or clear mechanism for changes in thunderstorms and tornadoes</p> <p>No clear/strong trends in overall storminess; evidence that storm tracks are shifting northward through the Northern Hemisphere</p>	<p>Droughts expected to be exacerbated by higher temperatures</p> <p>Decreases in rainfall in the Southwest expected to increase frequency/severity of drought</p> <p>Wildfires expected to be more extensive and severe</p>

Joe Casola, C2ES
Staff Scientist, Director of Science and Impacts
Center for Climate and Energy Solutions

Heavy Rainfall, Flooding, and Sea Level Rise

National and Regional Trends Regional Trends

Increases in heavy rainfall, esp. in East and Midwest

Riverine streamflow records show both increases and decreases in flooding

Many coastal areas are experiencing frequent/severe flooding

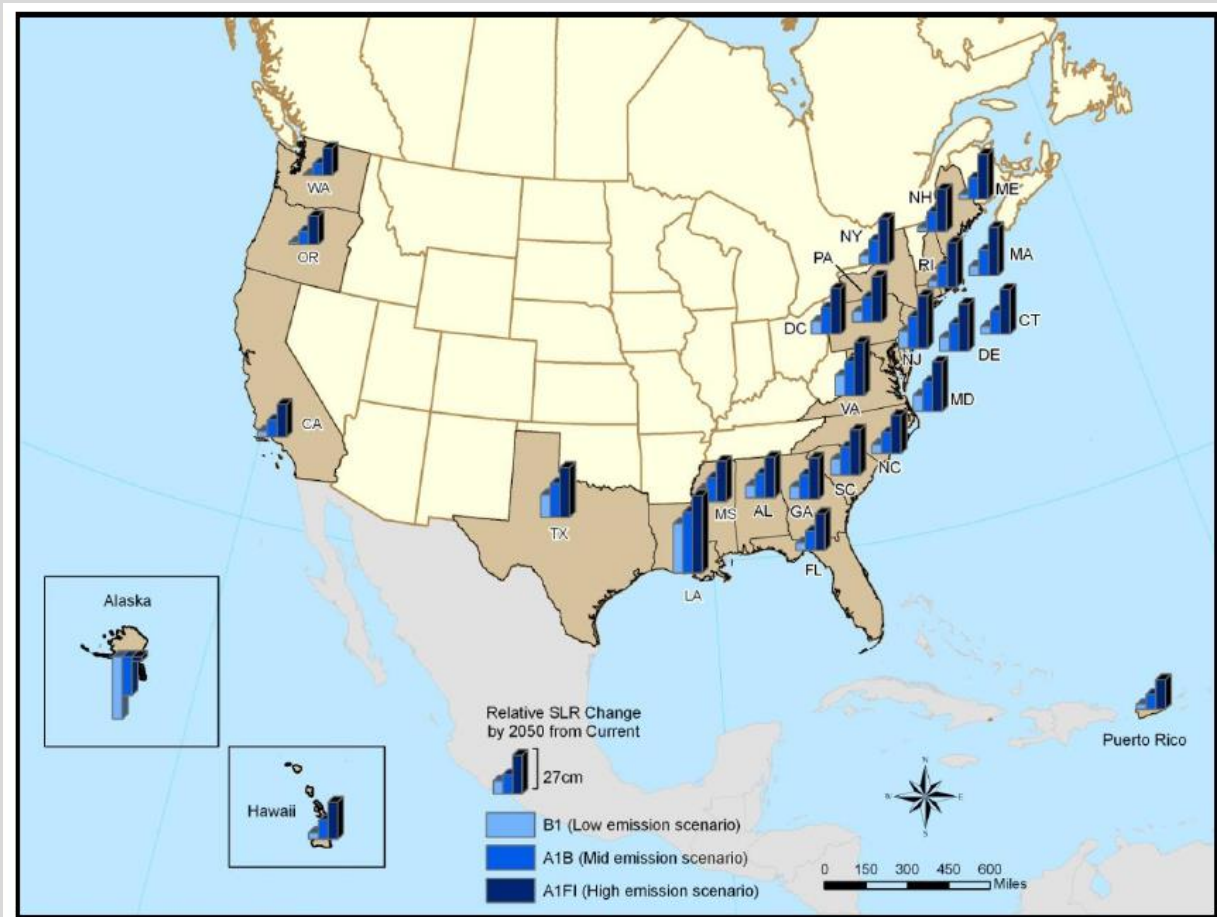
In many Western locations, changes in snow accumulation and snowmelt alters the timing of peak flows

Projections

Atlantic tropical storms expected to become more intense, but potentially less frequent

Considerable uncertainty regarding the magnitude and direction of changes (if any) in overall storminess or thunderstorms/tornadoes

Projected Sea Level Rise, 2050 Relative to 2010



NCHRP 20-83(5)

**PARSONS
BRINCKERHOFF**

For Transit.....

Four climate change impacts affect public transportation assets and services:

↑ Intense Precipitation
(very likely, >90%)

- Flooding of track, bus ways, tunnels, lots, facilities
- Landslides

↑ Very Hot Days & Heat Waves
(very likely, >90%)

- Track buckling leads to slow order or derail
- Customer comfort issue
- Worker safety issue

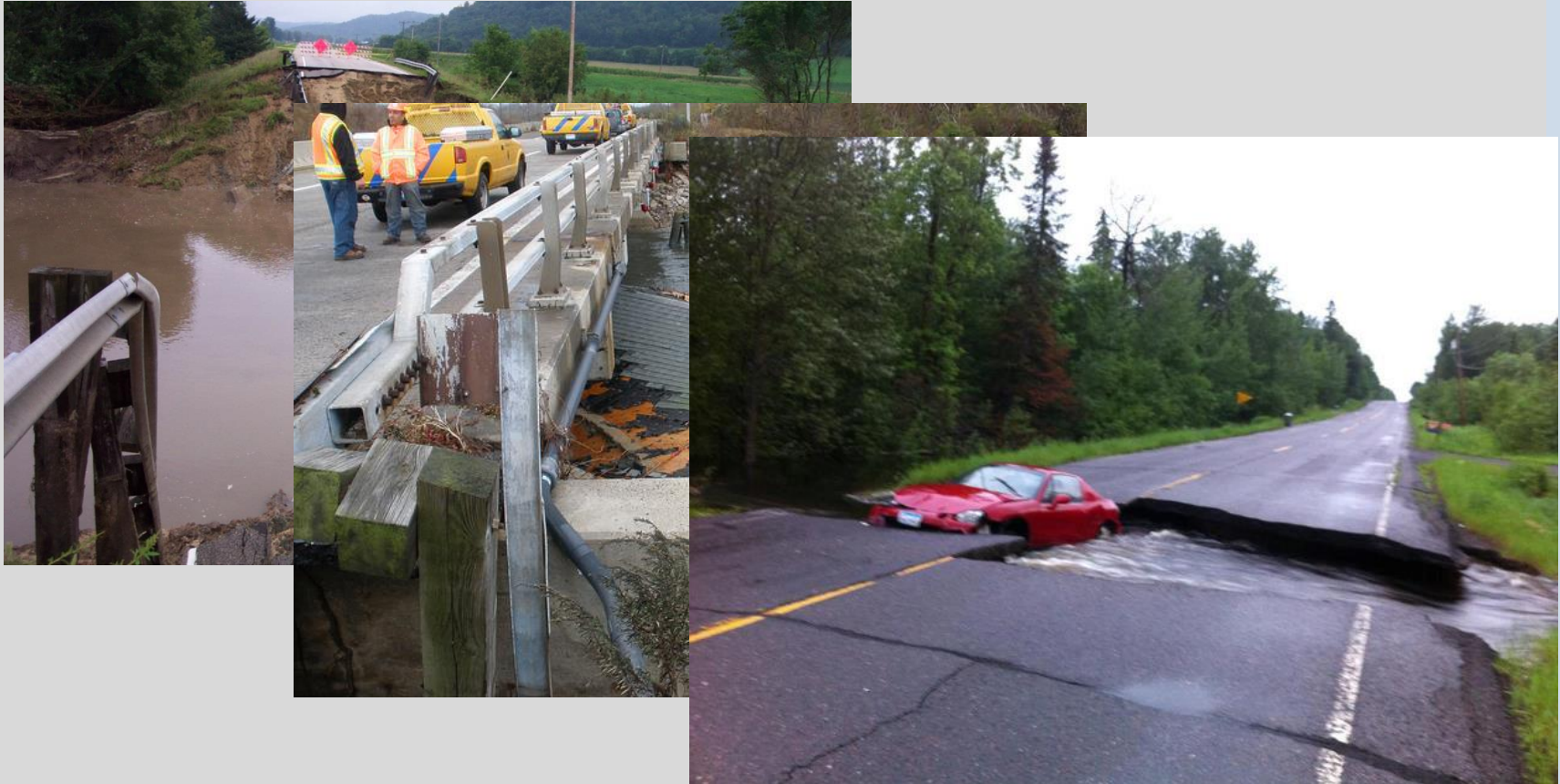
Rising Sea-levels
(virtually certain, >99%)

- Flooding of track, bus ways, tunnels, lots, facilities
- Higher groundwater level floods tunnels

↑ Hurricane Intensity
(likely, >66%)

- Flooding from storm surge, rain
- High winds debris, wind damage

4. Level of vulnerability

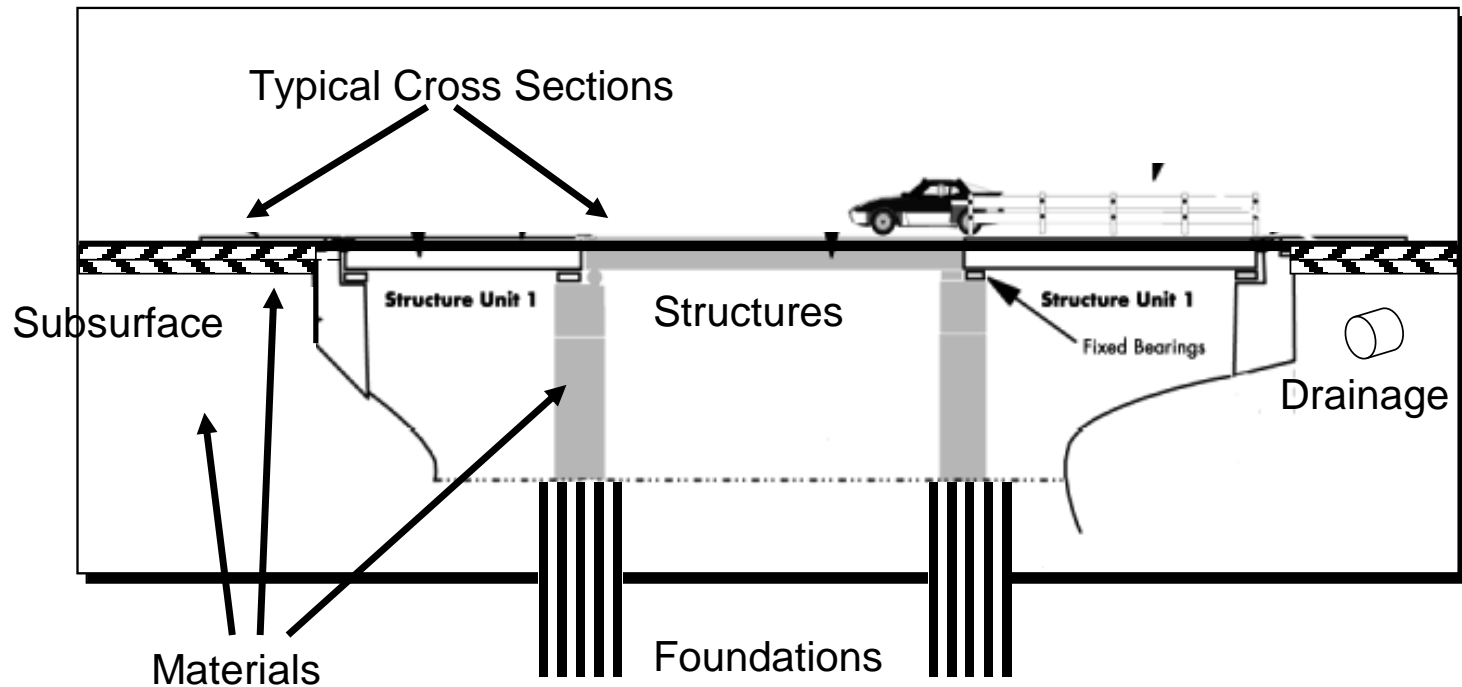


Level of vulnerability

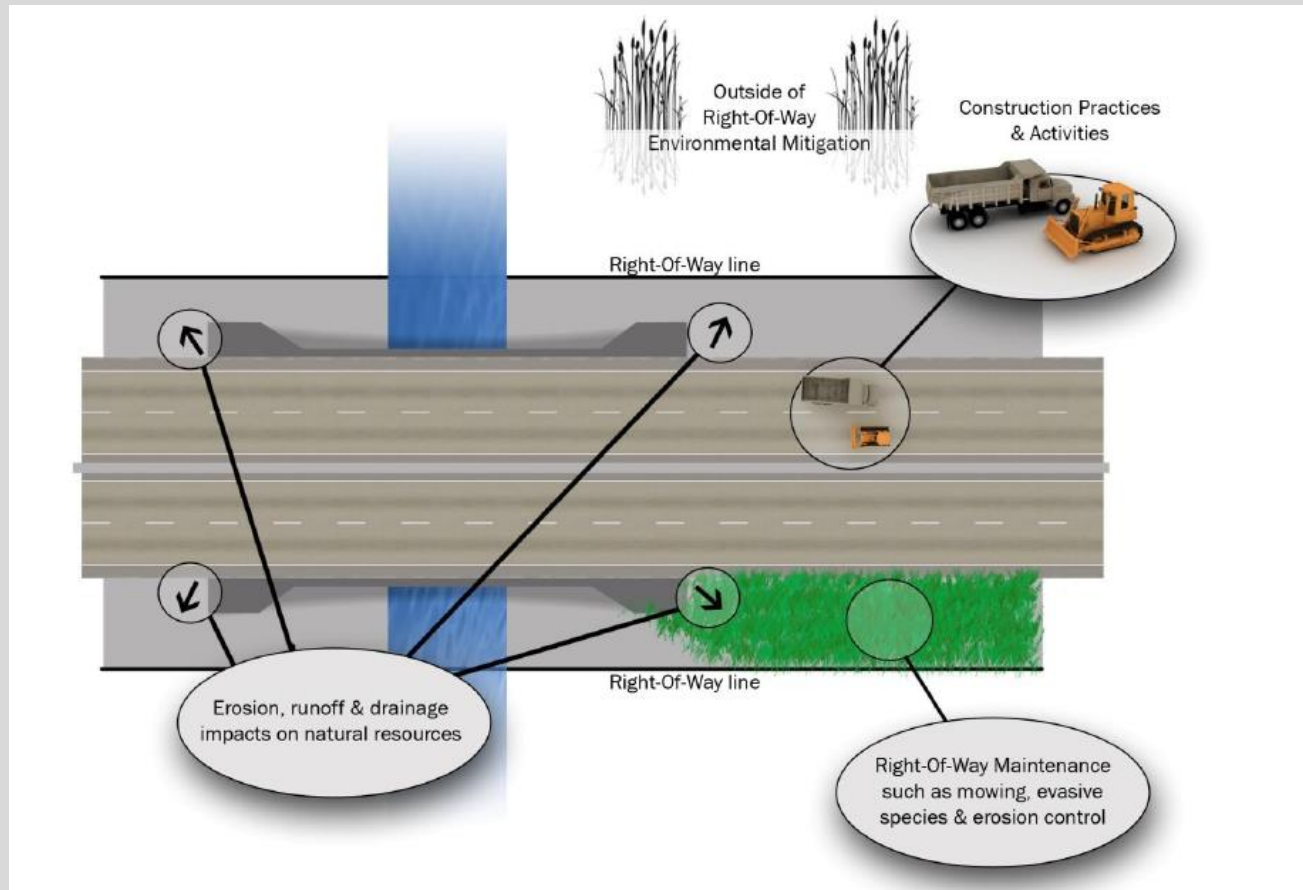


I-680 Iowa

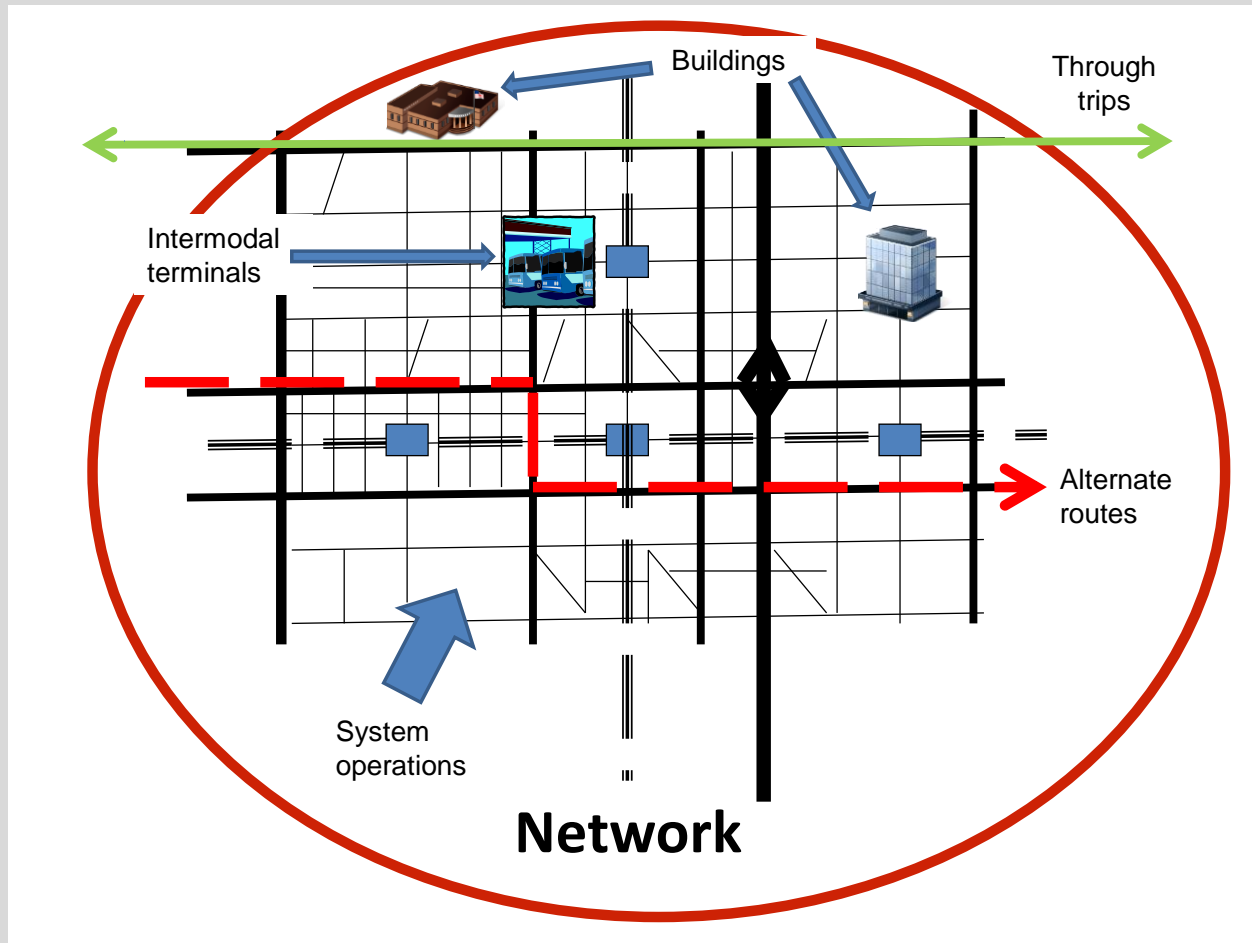
A Typical Road Segment



Corridor Impacts



Network Impacts

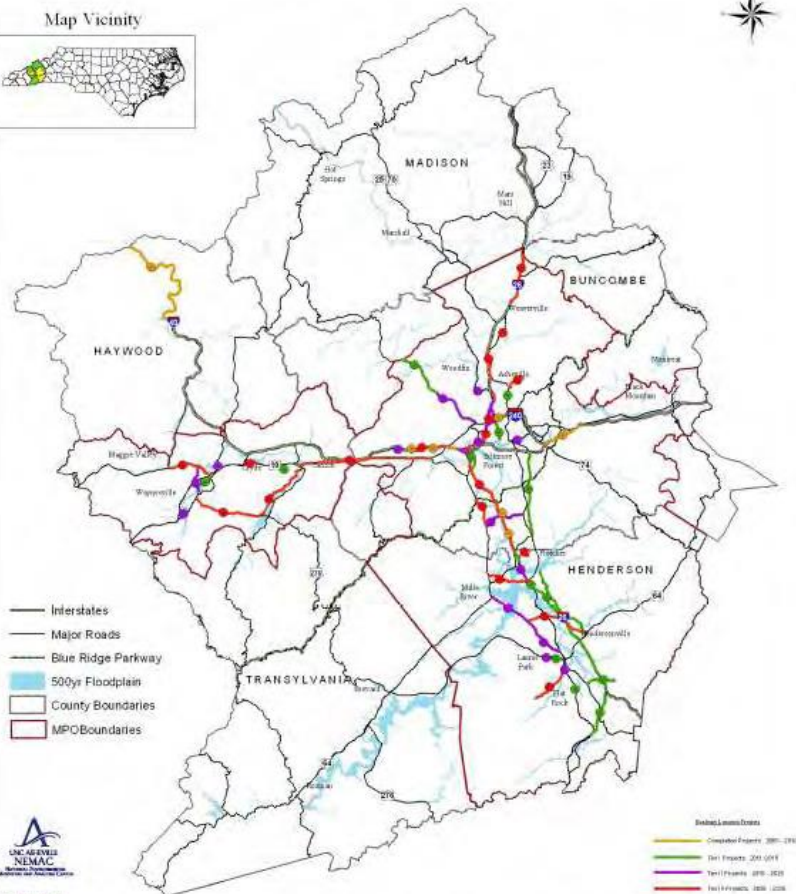


Asheville, NC

FLOODPLAINS

Land-of-Sky Regional Council Transportation Planning Area

Map Vicinity



The new 500 year floodplain data for this region indicates that a total of 5.6% of land area for the 5 counties is covered by a 500-year floodplain. Total Henderson County land area is covered by 8.6% of a 500-year floodplain.

Proposed LRTP projects were overlaid on maps of the region's 500 year floodplain, wildfire risk, and steep slopes (prone to landslides).

**PARSONS
BRINCKERHOFF**

64

Map Vicinity

A total of 298 miles of highways in the 5 county region intersect a 500-year floodplain.

Legend:

- Highways X Floodplains
- Interstates
- Major Roads
- 500yr Floodplain
- French Broad MPO
- County Boundaries

Scale: 0 to 20 Miles

Map Vicinity

Slope (Degrees)

- 0 - 25
- 25 - 83

Legend:

- Interstates
- Major Roads
- Blue Ridge Parkway
- County Boundaries
- MPC Boundaries

Historical Landmarks

- Completed between 1890 - 1900
- 1900 - 1910
- 1910 - 1920
- 1920 - 1930

Distance between points

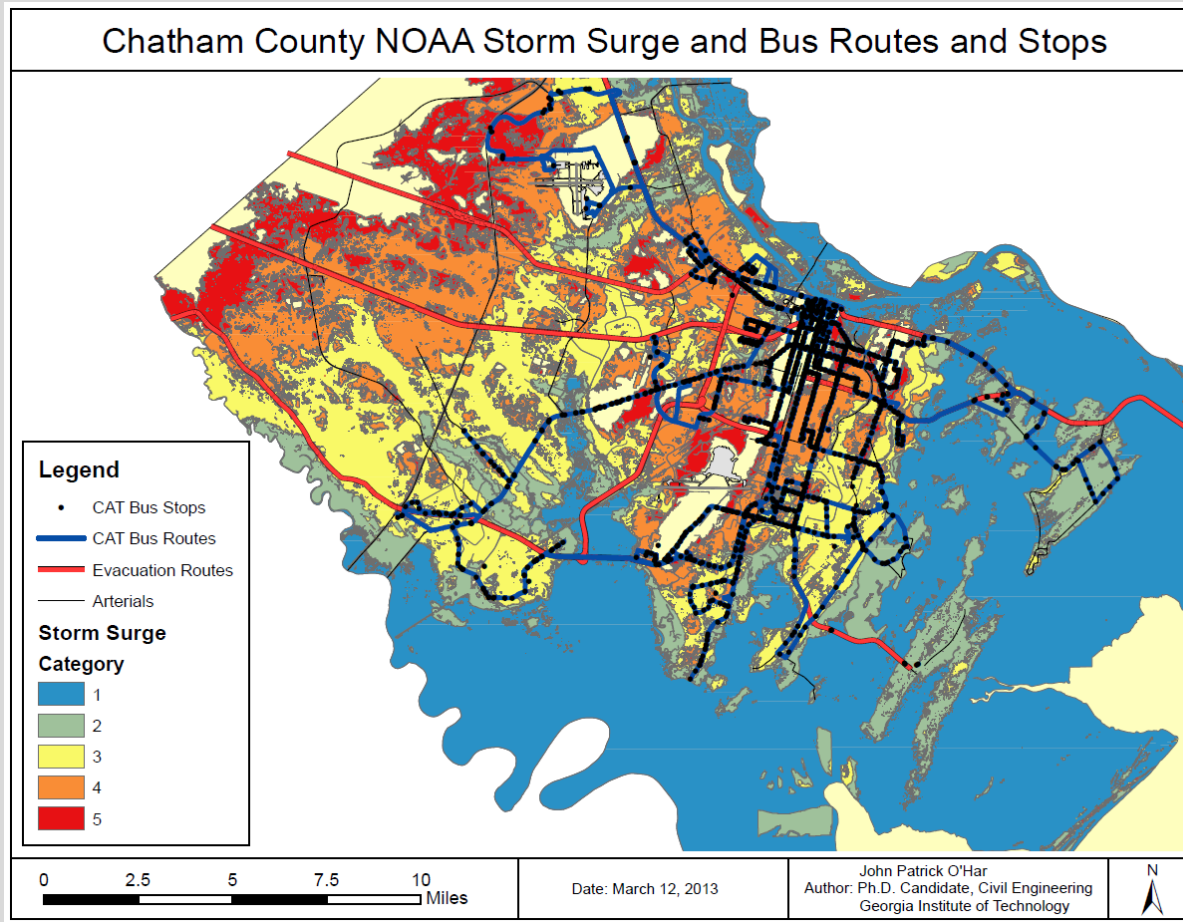
- Completed between 1890 - 1900
- 1900 - 1910
- 1910 - 1920
- 1920 - 1930

The new 500 year floodplain data for this region indicates that a total of 5.4% of land area for the 5 counties is covered by a 500-year floodplain. Total Henderson County land area is covered by 5.6% of a 500-year floodplain.

0 5 10 Miles

**PARSONS
BRINCKERHOFF**

Chatham County (Savannah)



5. Risk Assessment

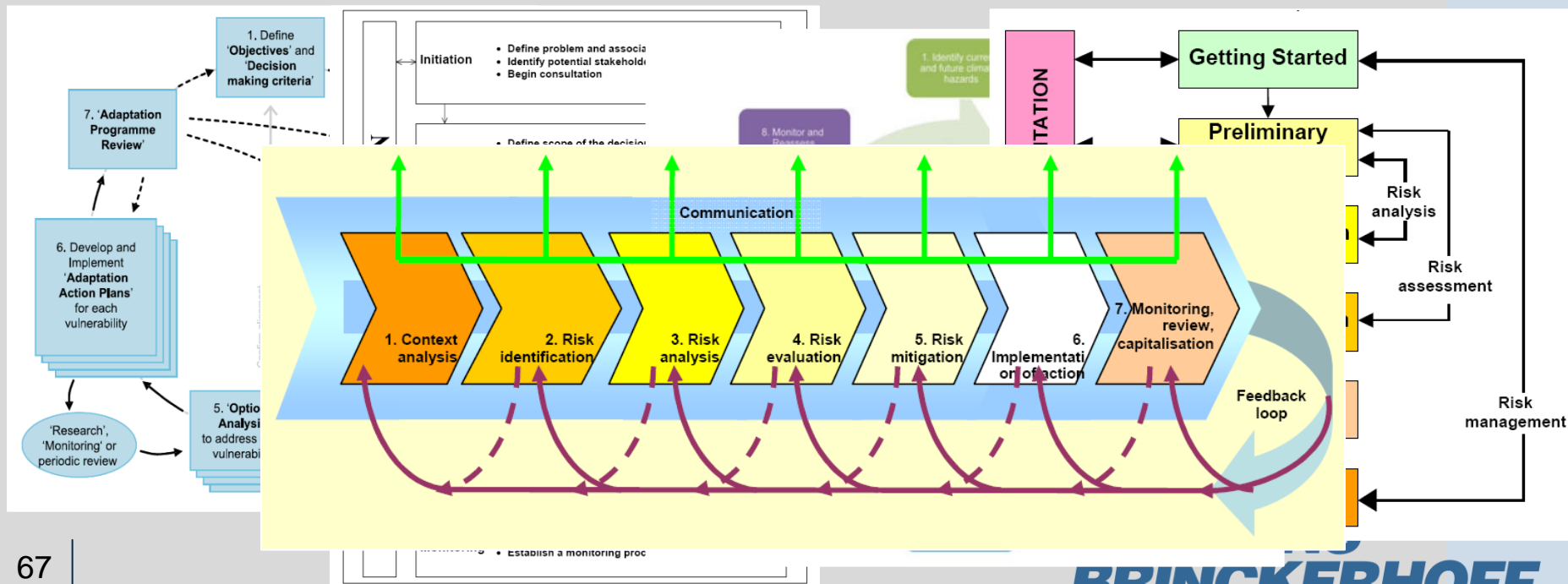
Risk =

[Probability of Climate Event Occurrence x
Probability of Asset Failure x
Consequence or Costs]

Risk Assessment

Risk-assessment & management methodologies

- Existing standards (AS/NZS 4360:2004, ISO 31000:2009)
- Existing corporate, enterprise risk-management
- Ad-hoc risk and/or vulnerability assessment frameworks



Commonalities

Expert panels, expert workshops

- Climate impacts (establishing context)
- Risk identification and analysis

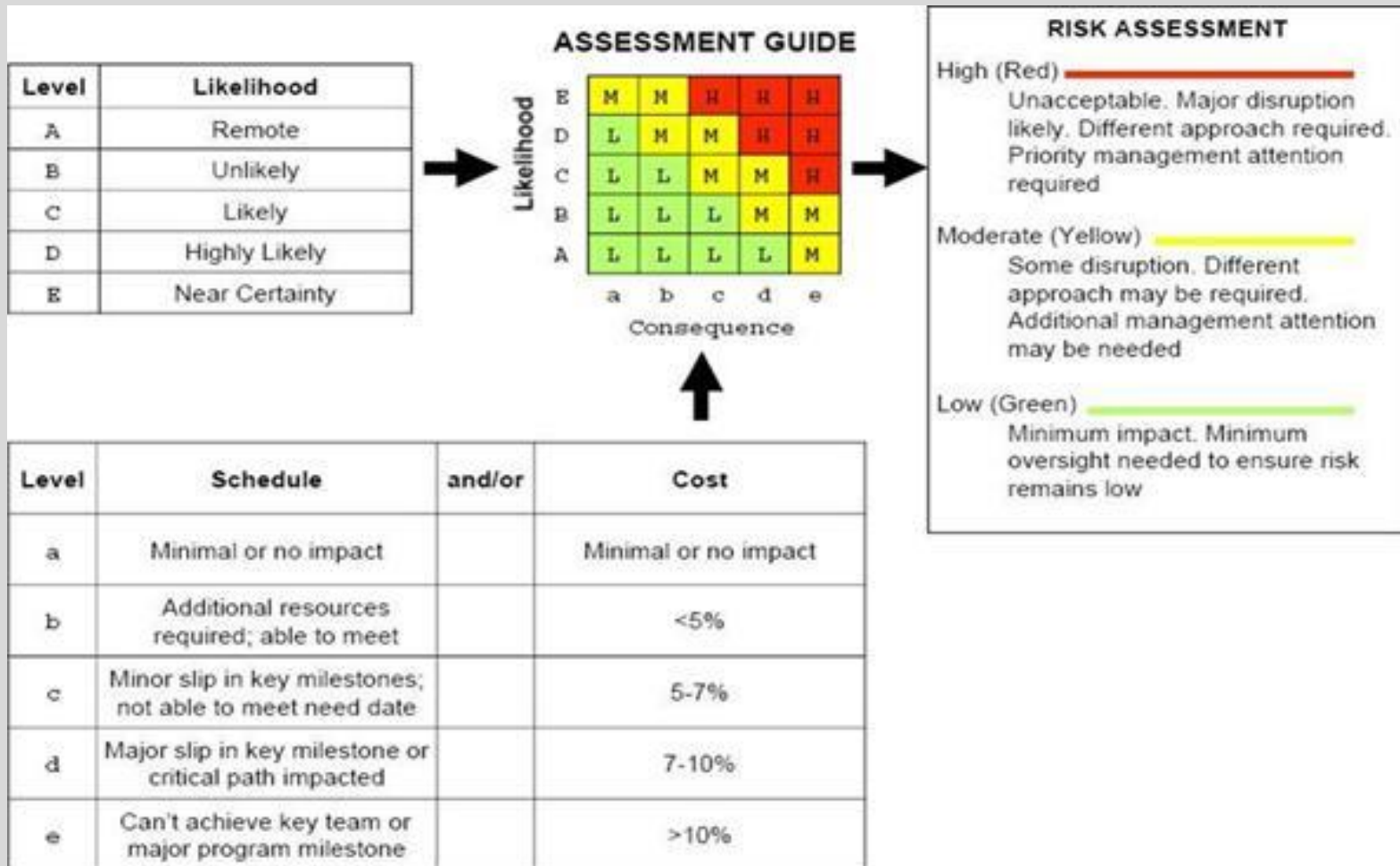
Risk matrices

- Risk prioritization

Qualitative or semi-quantitative

- High/Med/Low vs. discrete risk scores

Matrix Approach



MTC Assessment

		Consequence				
Likelihood		1	2	3	4	5
	1	2	3	4	5	6
	2	3	4	5	6	7
	3	4	5	6	7	8
	4	5	6	7	8	9
	5	6	7	8	9	10
Risk		Low		Moderate		High

Unacceptable, major disruption likely; priority management attention required.

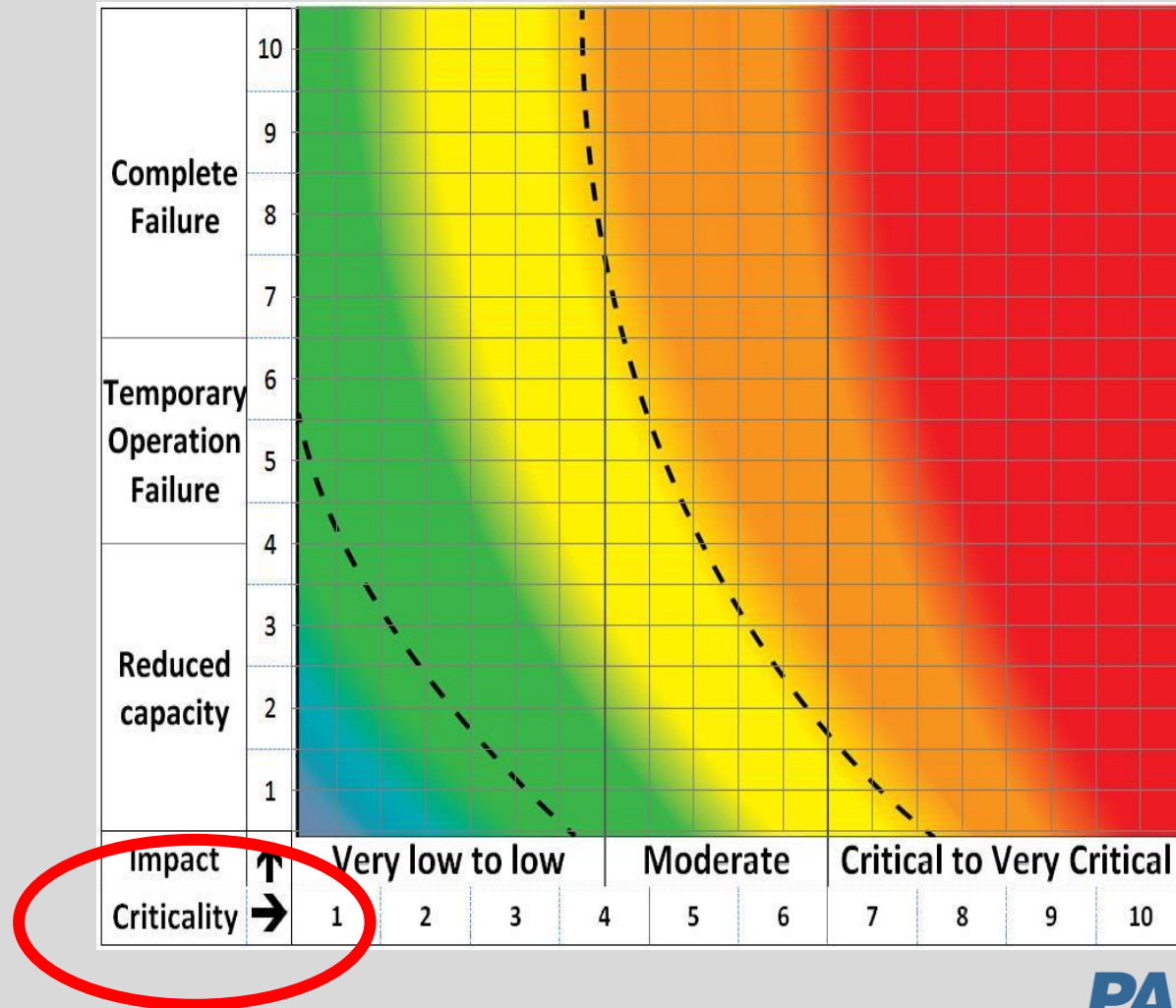
Moderate Risk (Orange)

Some disruption; additional management attention may be needed.

Low Risk (Green)

Minimum impact; minimum oversight needed to ensure risk remains low.

Washington State

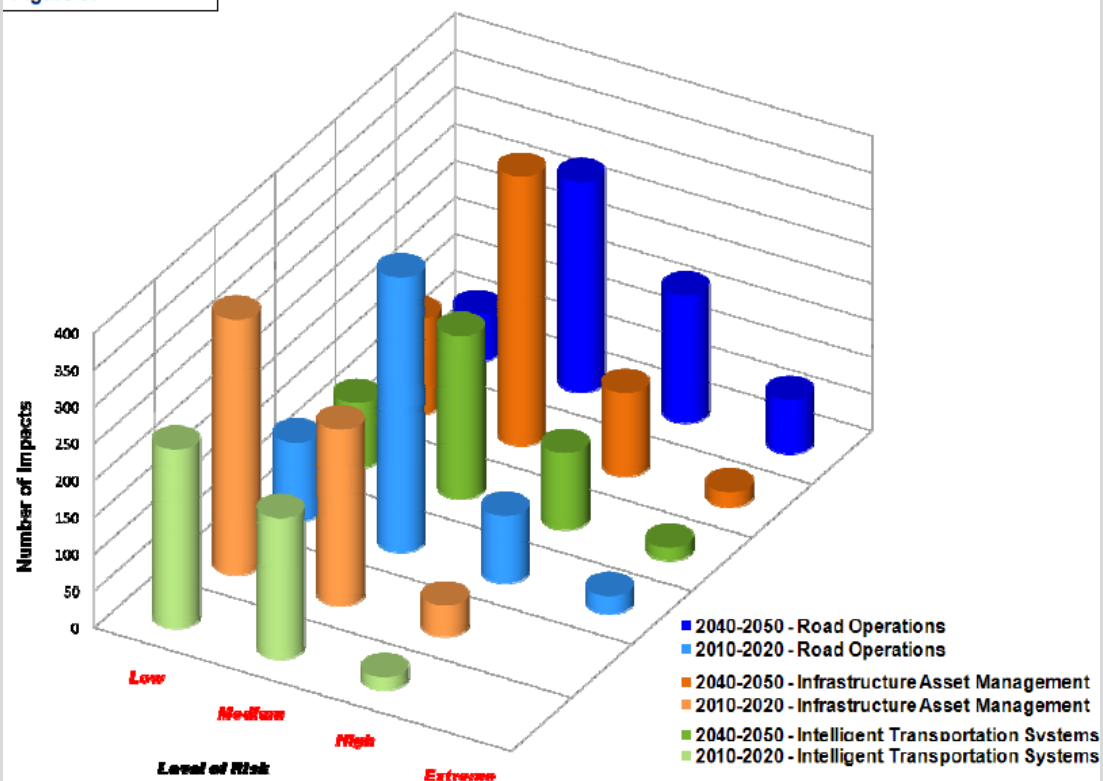


Toronto



Figure 5:

Transportation Services Overall Risk



Chattanooga

Stressor	Potential Impacts	Consequence	Frequency	Strategies
Extreme Precip.	Flooding	Damage to levee Damage to I-75 Disruption to I-24	Today, once every 100 years, but increasing	Raise levee redesign
Extreme Temp.	Significant Expansion	Major damage Disruption	Unknown, but increasing	Alt. route planning
	Slight Pavement Expansion	Major deterioration	Unknown, but increasing	Pavement improvements

Adaptation Strategies



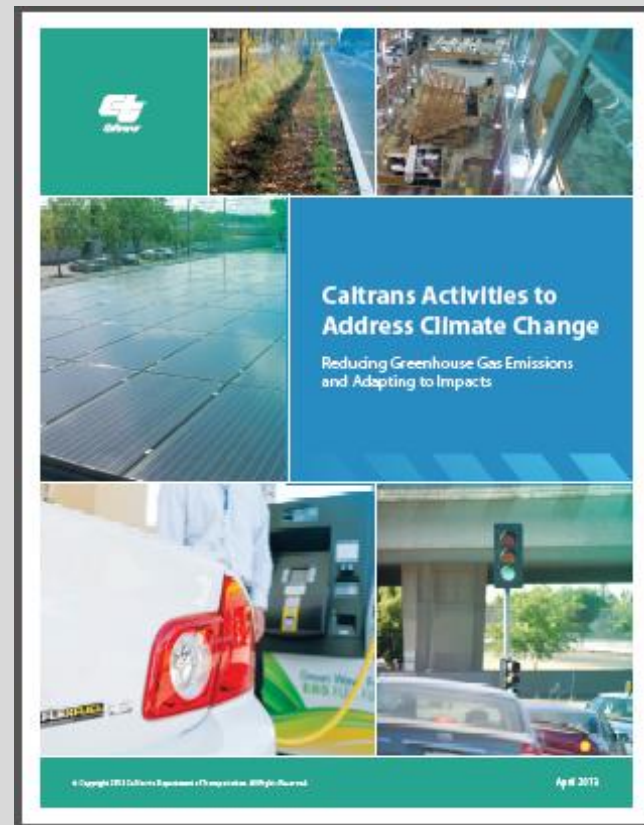
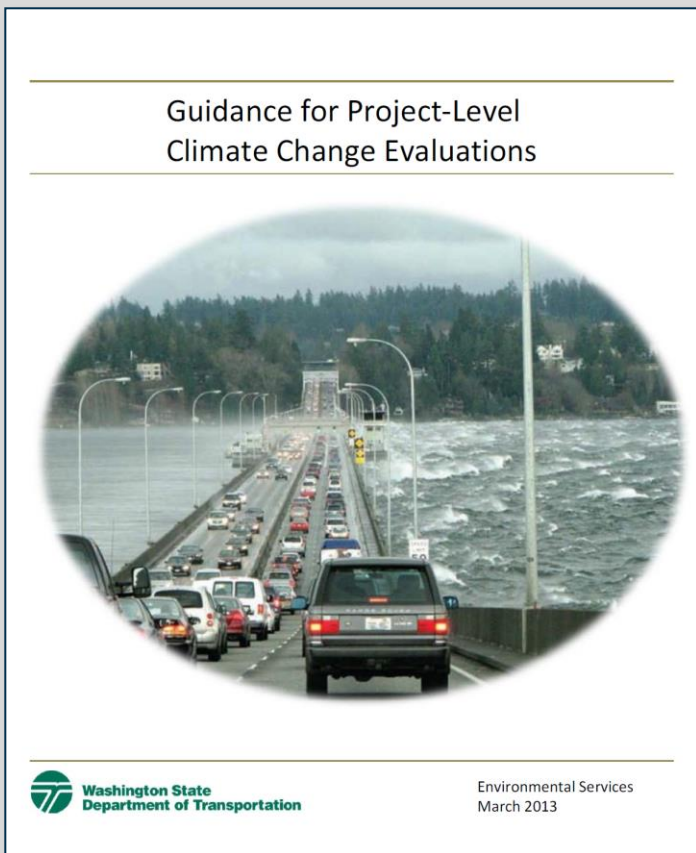
Actions and Opportunities

- Linkage to policy/strategic directions
- Transportation plans and special planning studies/operations plans
- Data collection and data management
- Linkage to asset management
- System-wide risk assessment and prioritization approach

Actions and Opportunities

- Project level planning and evaluation
- Adaptive infrastructure designs
- Graphical tools for presenting information
- Communication and public info.

Some Guidance



Asheville, NC

Coordinate with the region's local governments and planning partners to link transportation with land use.

Use future scenarios in transportation and land use planning to design systems that are robust and resilient compared to just being optimized for current conditions and economics.

Options for the Treatment of Risks

- Future-proofing of designs
- Retro-fit solutions
- Developing contingency plans
- Updating operating procedures
- Monitoring
- Research

There are the Little Things....



Vent Cover

There are the Little Things....



Source: Kansas City Board of Parks Commissioners, Presentation: Troost BRT Streetscape, January 2009

Figure 4-6
*Kansas City Bus Rapid
Transit Station Rain
Gardens*

BRT Station Landscaping



Figure 4-7
*Construction of
Pervious Concrete
Parking Lot that
Allows Stormwater
to Seep into Ground,
Kansas City*

*Courtesy of Kansas City
Area Transportation
Authority*

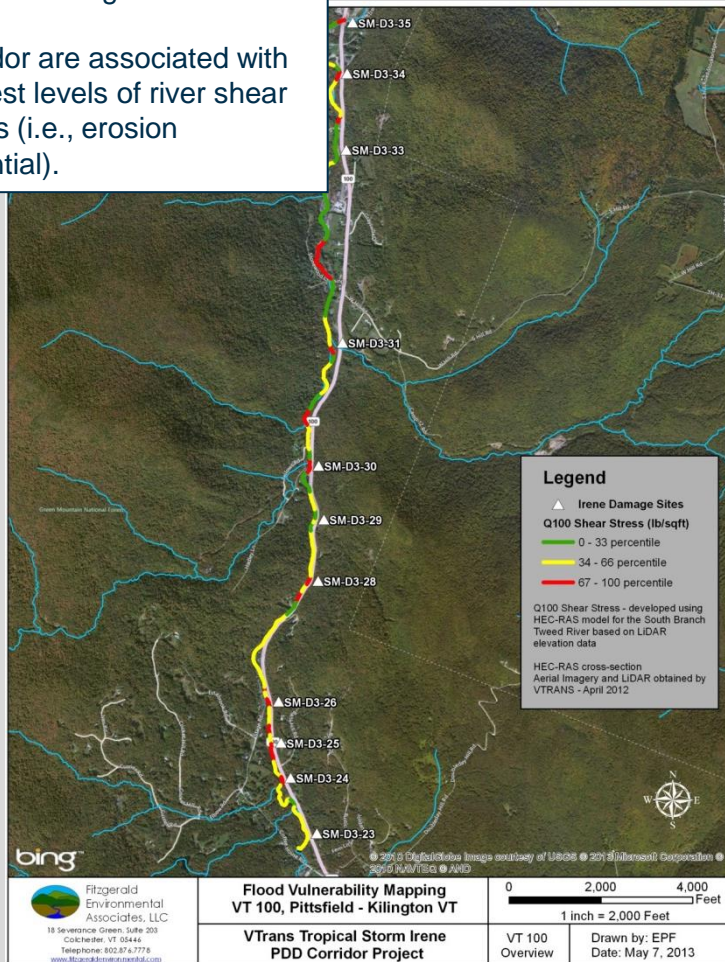
There are the Little Things....



Bus Stop Inventory Shade Types

Forecasting: Flood Vulnerability Mapping Using LiDAR Data -- Vermont

8 of 11 damage sites in Rt. 100 corridor are associated with highest levels of river shear stress (i.e., erosion potential).



Process-based approach to identify and prioritize risk in river-roadway corridors:

1. Hydrologic and hydraulic modeling (HEC-RAS) to quantify river and floodplain erosion potential.
2. LiDAR slope mapping to identify slopes $>100\%$ in between roadway and river.
3. Identify areas of roadway with limited relief from river that are susceptible to erosion during flood events.

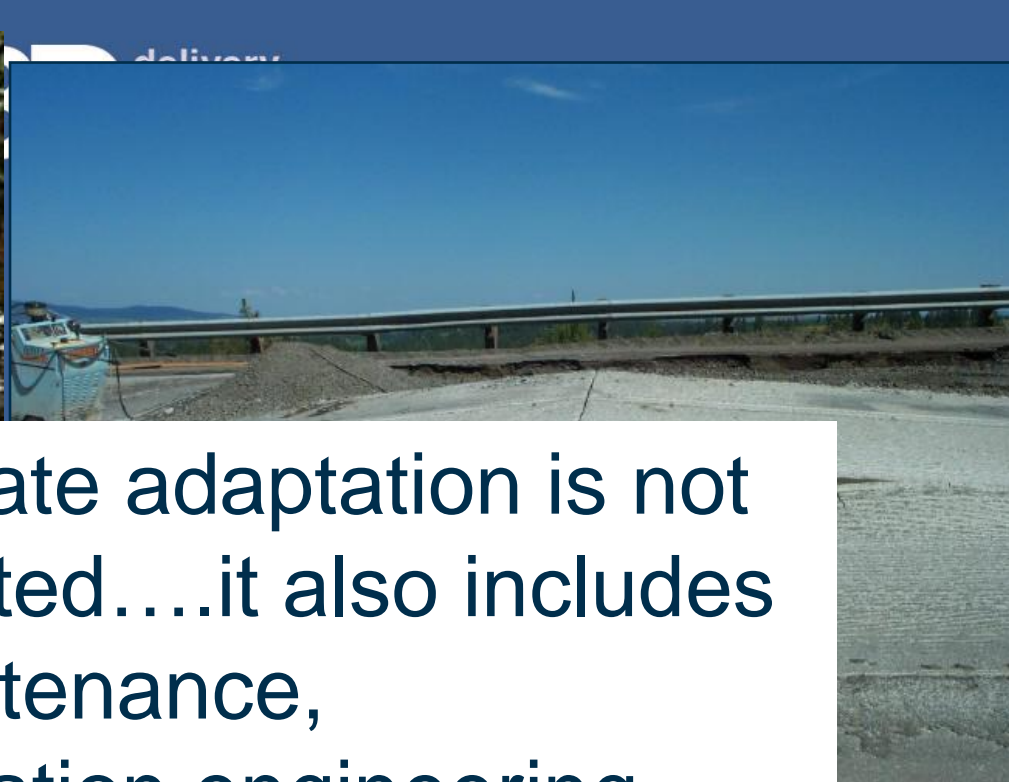
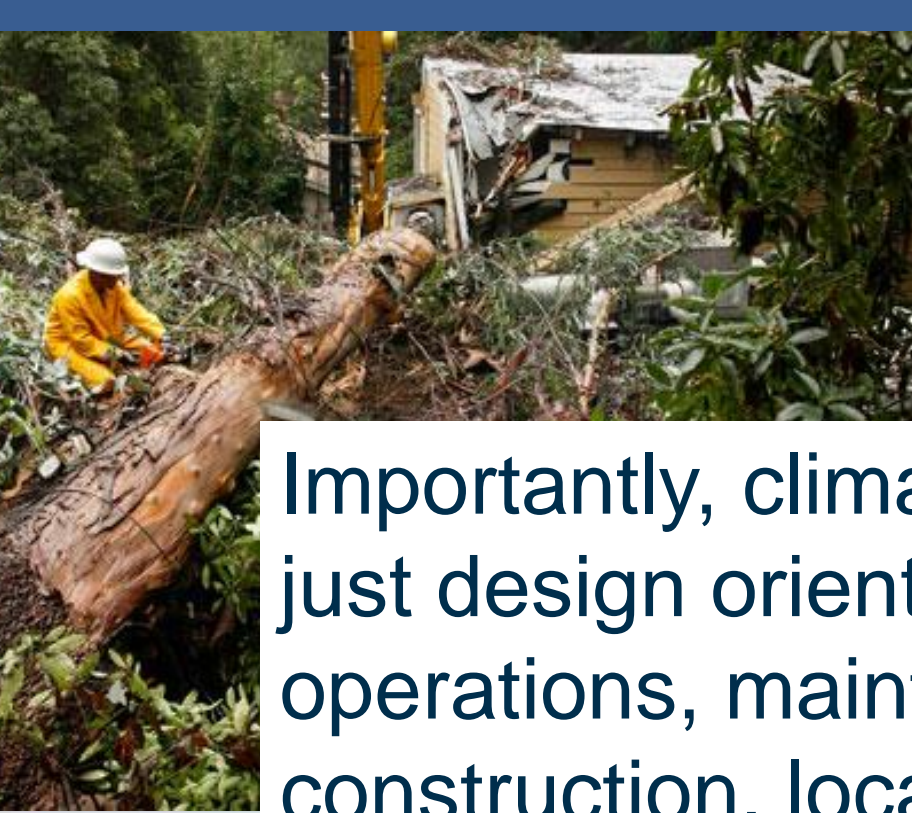
Expedited Replacement



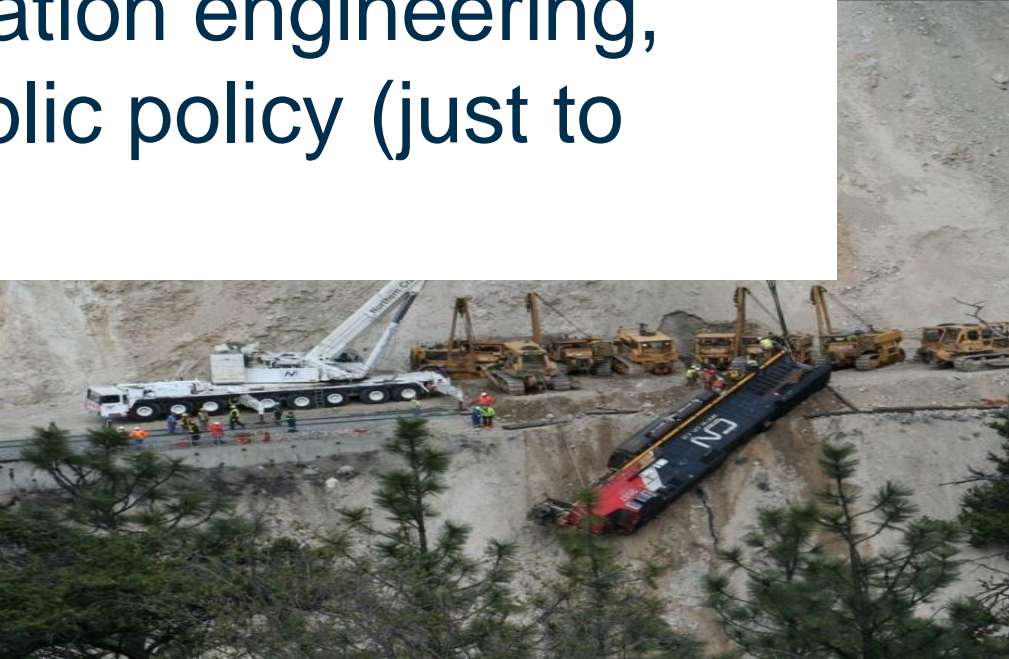
**Bridge Washed Out
August 19th, 2007**

**Bridge Opened to Local
Traffic Nov. 16th, 2007**





Importantly, climate adaptation is not just design oriented....it also includes operations, maintenance, construction, location engineering, land use and public policy (just to name a few).



Meyer's Top Ten O&M “Things To Do”

1. Culverts: Keeping culverts debris free and maintained to handle above average flows.
2. Bridge Scour: In high risk river/stream basins, protecting bridge columns and piers from higher than average flows during extreme precipitation events to reduce probability of bridge scour.
3. Evacuation Routes: In coastal and flood prone areas, developing and operating effective evacuation routes.
4. Traveler Information: Developing effective public and traveler information systems/services that can be used during weather emergencies to inform travelers of travel options.

Top Ten O&M “Things To Do”

5. Pre-Positioning Materials and Equipment: Developing strategies for responding to transportation system and facility disruptions due to weather-related events, including pre-positioning replacement materials in vulnerable areas
6. Workforce Protection: Protecting O&M workers from extreme temperatures during day-to-day activities.
7. Mudslide and Landslide Strategies: Identifying facility locations vulnerable to mudslides or landslides, and developing appropriate strategies to minimize such risk.

Top Ten O&M “Things To Do”

8. Back-Up Power: Putting in place power back up for electrical devices in areas prone to extreme weather events, especially for traffic signals.
9. Early Warning Indicators: Incorporating “early warning indicators” for potential extreme weather-related risks into asset and maintenance management systems.
10. Landscaping and Vegetation: Where appropriate, using drought-proof landscaping and vegetation, and multi-culture families of vegetation

Finally, if you think you've got challenges.....

